

DIAGNOSIS OF UNDERLYING PHYSICAL FITNESS TRAITS OF ADULTS' SELF-
REPORTED PHYSICAL FUNCTION

BY

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DISSERTATION

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ABSTRACT

Physical function decline is a common trajectory with aging. Physical function questionnaires have been widely used in occupational/physical therapy to assess adults' physical function. However, most research only focuses on physical function itself. Rich patterns or profile information of the underlying physical fitness embedded in physical function questionnaires were overlooked. In addition, the associations between chronic diseases and physical fitness trait deficiencies are still less well known. Therefore, the main purpose of this study is to apply a diagnostic model that can help diagnose adults' underlying physical fitness traits based on their self-reported physical function.

This study invited three experts in the areas of physical function and physical fitness to develop a Q-matrix to be used in the diagnostic model development. Three diagnostic models were employed with the developed Q-matrix to an existing dataset (Patient-Reported Outcomes Measurement Information System [PROMIS], N = 942, 51.17% women). The most appropriate diagnostic model was selected and participants' physical fitness trait statuses were estimated. Descriptive analyses and multiple logistic regressions were conducted to identify associations between physical fitness trait deficiencies and age/chronic diseases. A secondary data source of physical function questionnaires and performance-based fitness tests from a Chinese Parkinson's disease group (N = 45, 60% women) was used to cross-validate the diagnostic model.

The results showed that the prevalence of several physical fitness trait deficiencies gradually increased with aging, even after controlling for other demographic variables including sex, race, education level completed, marital status, family income, body weight status, and chronic diseases. The odds of all five physical fitness trait deficiencies were significantly higher

in obese individuals than in normal weight individuals. This study found significant relationships between some chronic diseases and physical fitness trait deficiencies. The validation results confirmed that the diagnostic model selected by this study can be used to diagnose people with deficiencies in lower-body muscular strength, upper-body flexibility, aerobic endurance, balance, and fine motor skill. This study contributes to exercise intervention and program design by paying attention to stressing the importance of physical fitness diagnoses.

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CHAPTER 1: INTRODUCTION

This chapter provides an introduction about adults' physical function decline in the United States. The relationship between physical fitness and physical function is introduced. To diagnose the status of physical fitness for people with functional decline, diagnostic models as new statistical techniques in kinesiology are discussed.

Physical Function

The ability to perform activities of daily living has been commonly used to determine a person's functional status (Rubenstein, Schairer, Wieland, & Kane, 1984). The level of physical function, according to Kalache and Kickbusch (1997), rises in childhood and peaks in early adulthood, and then it starts to decline at a speed mainly determined by health status and daily health behaviors. In fact, over a quarter of U.S. adults have one or more self-reported functional limitations (An, Chiu, Zhang, & Burd, 2015). In this study, physical function decline was used as a general term to refer to declined physical function ability to perform daily life tasks. Physical function decline is regarded as a common trajectory with aging due to its contributions to decreased quality of life, increased risk of disability, falls, fractures, depression, and raised healthcare costs (Fried, Bradley, Williams, & Tinetti, 2001; Schieman & Plickert, 2007; Wolinsky et al., 2007). Many factors were found to be linked to physical function decline, such as foot problems, number of medications (Sibbritt, Byles, & Regan, 2007), reduced physical activity, long periods sedentariness (O'Caoimh et al., 2014; Seguin et al., 2012), and aging (Short et al., 2005).

Physical function decline could result in health issues. For example, physical function decline predicts the onset of "preclinical disability" (Fried, Herdman, Kuhn, Rubin, & Turano,

1991). In addition, increased risk of functional decline among community-living older people was demonstrated to be associated with cognitive impairment, depression, comorbidity, low frequency of social contacts, and poor self-perceived health (Stuck et al., 1999). Meanwhile, increasing evidence suggests people with chronic diseases, such as diabetes, hypertension, dyslipidemia, heart disease, and cancer, are at higher risk for functional declines (Bayliss, Bayliss, Ware, & Steiner, 2004).

Physical Activity, Fitness and Function

To promote physical function, the most effective way is to find the deficiencies of physical fitness that causing physical function decline and then design personalized physical activity interventions to improve individuals' physical function. Yorston, Kolt, and Rosenkranz (2012) reported that higher levels of daily physical activity were linked to better physical function in adults over 45-year old. Regular physical activity was found to be associated with promoted physical function after a 4-month community intervention (Fitzpatrick et al., 2008). Physical fitness could possibly be ultimately enhanced through the process of regular physical activity. The amount and rate of physical fitness improvement would be varied among people with different health conditions. Overall, physical activity has been demonstrated its benefits for people's health and physical fitness from different perspectives (Corbin & Pangrazi, 1993).

Physical fitness is defined as a set of attributes that people have or achieve relating to their ability to perform physical activity (U.S. Department of Health and Human Services, 1996). Previous evidence suggests that the ability to perform a physical task is determined by a threshold level of physical fitness, such as aerobic capacity, muscular strength, and endurance (Brill, Macera, Davis, Blair, & Gordon, 2000). Physical fitness programs were demonstrated to be beneficial for older adults' physical and mental well-being, carrying out physical and

emotional roles, general health, social functioning, and increasing level of vitality (Dorgo, Robinson, & Bader, 2009). As a result, to promote the construction of effective exercise interventions for preserving the function and independence of older adults, understanding the contribution of physical fitness components to functional performance is very important (Singh, Paw, Bosscher, & Van Mechelen, 2006).

Physical fitness is considered one of the most essential health markers and predictors for cardiovascular disease and all causes of morbidity and mortality (Ortega, Ruiz, Castillo, & Sjöström, 2008). Low levels of physical fitness were confirmed to be associated with an increased risk of all-cause mortality and cardiovascular disease mortality (Blair et al., 1995). It also has been evidenced that physical fitness is a key determinant of whole-body or total health, and can support the individual to accomplish life goals (Paffenbarger et al., 1990).

Therefore, to design individualized physical activities or exercise interventions to prevent people from further functional decline or possibly becoming disabled, the underlying deficiencies of physical fitness for people with functional decline need to be explored. However, traditional assessment of adults' physical function in physical therapy (PT) and occupational therapy (OT) has been limited to the physical function itself and restricted on reporting the physical fitness problems but the level of physical function. These traditional assessments of physical function questionnaire ignored that physical fitness is the key to prevent physical function decline, which makes exercise prescription and intervention difficult, if not possible. Even though numerous widely used physical function assessment tools were used to measure function status, the underlying physical reasons such as fitness deficiencies are rarely revealed by current physical function assessment methods.

Assessment Issues for Physical Function

Physical function in occupational therapy or physical therapy is commonly measured using questionnaires concerning daily life activities. To assess individual's physical function levels, total scores of the physical function questionnaires, which were constructed based on classical testing theory (CTT), have been widely used in most studies to estimate physical function status (Bayliss, Bayliss, Ware, & Steiner, 2004; Kington & Smith, 1997). Yet, using total score has several limitations. For example, participants' ability could be overestimated or underestimated using only total scores (Zhu, 1996) and participants' characteristics and questionnaires' characteristics cannot be separated (Hambleton, Swaminathan, & Rogers, 1991).

To overcome the limitations of using a total score based on CTT, item response theory (IRT), which is based on test construction, has been employed to estimate individuals' physical functioning ability (e.g., Fan, 1998). Overall, IRT offers more information about the items and greater flexibility in scoring and scaling assessed traits compared to CTT. Though IRT provides many advantages compared to CTT, the long length required of tests based on IRT still limit its wide application in physical function measurements. Thus, computerized adjustment testing (CAT) as a modern testing mode, not only tailors the test length but also provides uniformly precise scores for different examinees. Therefore, CAT is regarded as a comprehensive and systematic assessment of physical function with the potential to improve the precision and efficiency of traditional disability evaluation process (McDonough et al., 2013). To address limitations of lacking uniform precision and long length required of tests based on IRT, the Department of Medical Social Sciences of Northwestern University, with support by the National Institutes of Health (NIH), designed a CAT system to measure participants' individualized physical function limitations (Bruce et al., 2009; PROMIS, 2016).

Diagnostic Assessment Methods

While the more advanced measurement model and methods (e.g., IRT and CAT) have been applied to physical function assessment, the underlying physical fitness traits of the commonly used physical function assessments have not been identified and documented. As a result, rich patterns embedded in the physical functional measures are ignored, and the associations between chronic diseases and underlying physical fitness profiles are still inconclusive. To find the possible underlying reason for the physical function limitation, more physical fitness information should be provided in the diagnostic analysis. Applying the latest diagnostic measurement models (Gierl, Alves, Roberts, & Gotzmann, 2009; Leighton & Gierl, 2007; Lutz, 2012) could identify underlying physical fitness traits from the commonly used physical function questionnaires, and detect physical fitness profiles which can be linked to chronic diseases. Fortunately, the cognitive diagnosis model (CDM), widely used in educational assessment to measure the probability of mastery or nonmastery of predefined skills or attributes in one test, could address this need.

CDM was first developed by Fischer (1973) using a linear logistic test model to create a statistical model for a cognitive diagnostic assessment. It expanded rapidly after a seminal chapter about the interdependency of cognitive psychology with psychometrics was published by Snow and Lohman (1989). It was widely utilized to address the need to provide examinees' cognitive characteristics and richer reporting practices in the fields of cognitive psychology and educational measurement (Snow & Lohman, 1989). For the participants involved in a test, each individual's ability on the predefined skills and attributes derived from test items, can be estimated by using cognitive diagnosis models (Henson, Templin, & Willse, 2009). Compared with CTT and traditional IRT, CDM provides more information about the underlying reasons for

why participants did not perform well based on skill mastery or nonmastery analyses. This diagnostic information about mastery or nonmastery for skills from CDM can benefit individuals in multiple ways. Many studies demonstrated the advantages of CDM application in educational and psychological areas (Lee, Park, & Taylan, 2011). For example, CDM was used in the language assessment education field, in which a reasonable set of dichotomous attributes according to items was verified using CDM (Jang, 2005). It was also applied in the assessment of psychological disorders and social science areas (Templin & Henson, 2006). According to the classification framework of models in CDM, two sorts of distinctive models are commonly used: compensatory models and non-compensatory models. Non-compensatory models can be divided into two different models which are conjunctive and disjunctive models. Different models have various specific assumptions of how participants' performance will be influenced by predefined skills (Henson, Templin, & Willse, 2009).

Using above diagnostic measurement models, this study will identify underlying physical fitness traits of well-known physical function banks, derive individuals' physical fitness profile, and link them with chronic diseases. Upon the completion of this study, underlying physical fitness traits of the commonly used self-reported physical function questionnaire should be identified and the underlying physical fitness trait deficiencies should be able to be diagnosed, which could provide a solid foundation for the design of future exercise interventions for combating physical function decline among adults. Therefore, corresponding physical exercise interventions can be prescribed and provided to physical function declined adults based on diagnosed underlying physical fitness profiles. Then, preventing possible disability onset and maximizing well-being may be accomplished.

Hypothesis

1. Underlying physical fitness traits of commonly used physical function assessment may be identified and documented accurately; underlying physical fitness traits could be regarded as a more comprehensive and fundamental explanation for life quality status rather than using total scores generated from physical function assessments.
2. Individuals' physical fitness trait statuses can be estimated from a physical functional assessment using diagnostic models.
3. The associations between people's physical fitness trait deficiencies and age/chronic diseases may be established.
4. The estimated results of physical fitness trait statuses will be correlated with the physical fitness levels assessed by performance-based tests.

Purpose

The main purpose of this study is to apply diagnostic models that can help diagnose adults' physical fitness traits based on their physical function status. By applying the diagnostic model to data from a U.S. general population study and one Chinese Parkinson's disease study, the specific aims of this study are:

1. Identify the underlying physical fitness traits from a major self-reported physical functional assessment bank;
2. Derive individuals' physical fitness traits/profiles using the diagnostic model and diagnose individuals' physical strengths and weaknesses;
3. Examine the relationships between physical fitness trait deficiencies and age/chronic diseases;
4. Validate the diagnostic model by comparing the diagnosed physical fitness trait statuses

to performance-based physical fitness test scores.

Significance

The literature review has shown that traditional physical function questionnaire measurement typically ignores physical fitness, which is crucial to guide exercise prescription. Therefore, by applying the diagnostic model and finding the underlying physical fitness trait statuses behind the physical function questionnaire, this study evidenced physical fitness's importance linked with physical function and connected with physical activity design.

By using the diagnostic method proposed in this study, researchers or physicians could have a better understanding why participants have physical function limitations and what kind of exercises should be prescribed. This diagnostic information could guide physicians to design physical activity interventions according to patient needs. At the same time, people with functional decline could use this diagnostic method to find their fitness deficiencies through self-diagnose without physicians' help, which could encourage them to take actions on their own to prevent more physical function capacity loss and maybe even counter present loss. Specifically:

1. Providing preliminary empirical evidence on the underlying physical fitness traits of PROMIS physical function banks;
2. Providing a better understanding of the variability of physical fitness traits for people during aging and with specific chronic diseases;
3. Providing advices to the OT/PT to design individualized exercise and physical activity programs based on diagnosed physical fitness trait deficiencies;
4. Helping for adults with functional decline to self-diagnose fitness deficiencies and then possibly prevent them from becoming disabled to a certain extent if action is taken based on diagnosis.

CHAPTER 2: LITERATURE REVIEW

This chapter reviews physical function, physical fitness, psychometric foundations of physical function measurement, and the current gaps in physical function assessments. A detailed background of physical function decline and its relationship with physical fitness is also provided. The CDM statistical modeling technique, to be used to diagnose the status of physical fitness from physical function questionnaire, is also introduced.

Physical Function

Physical function is important for ensuring one's well-being and quality of life. Physical function, defined by Leidy (1994), is the ability to physically provide for the necessities of life, including normal life activities to meet basic needs, and to fulfill one's usual roles to maintain health and wellbeing. Therefore, the ability to perform activities of daily living has been commonly used to determine a person's functional status (Rubenstein, Schairer, Wieland, & Kane, 1984). Performance of physical function in daily life is a reflection of an individual's overall health and physical health. Several common chronic diseases such as arthritis and osteoporosis can result in physical function decline in the course of daily life.

Physical Function Decline

Physical function decline is a common trajectory with aging and warrants attention due to its prevalence and contributions to decreased quality of life, increased risk of disability, falls, fractures, depression, and healthcare costs (Fried, Bradley, Williams, & Tinetti, 2001; Schieman & Plickert, 2007; Wolinsky et al., 2007). In this study, physical function decline is used as a general term to refer to declined physical function ability to perform daily life tasks. Mobility

problems, such as walking, getting out of bed, sitting down, taking stairs, and getting in and out of transportation, are often an early manifestation of a decline in physical function and they are highly predictive of disability progression (De Vries et al., 2012). The specific relationship between physical function decline and disability is discussed in more detail below.

Physical function ability varies across the lifespan. According to Kalache and Kickbusch (1997), the level of physical function rises in childhood, peaks in early adulthood, then starts to decline at a rate mainly determined by health status and daily health behaviors. Physical function decline, as a substantial impairment in an individual's ability to effectively perform major life activities, is a strong precursor of morbidity and mortality (Huang et al., 1998; Maslow et al., 2011; Reuben, Rubenstein, Hirsch, & Hays, 1992).

Several existing studies reported the prevalence of physical disability and functional limitations among older adults in some developed countries. For example, in the United States, the prevalence of physical function decline among adults 65 years and older was 8.1% in 1987 (Wiener, Hanley, Clark, & Van Nostrand, 1990). Physical function decline has consistently occurred with the increasing of aging of the U.S. population. One study even has shown that over 25% of U.S. adults had one or more self-reported functional limitations (An, Chiu, Zhang, & Burd, 2015). Similarly, there are 30% of adults 65 years and older had mobility issues (Nordstrom et al. 2007). About 32% of men and 46% of women 59 years and older in the U.K. were found to be living with limited mobility (Syddall, Martin, Harwood, Cooper, & Sayer, 2009). In developing countries, studies revealed that 23.7% of Cambodian older adults 60 years and older experienced physical function decline in 2004 and 28.6% of Ethiopian adults 55 years and older encountered physical function problems (Teferra, 2005; Zimmer, 2008).

Risk Factors for Physical Function Decline

Many factors were found to be linked with physical function decline and physical disability, including non-modifiable risk factors (i.e., sex, race, and aging) and modifiable risk factors (i.e., lifestyle factors) (Payette, Gaudreau, Morais, Shatenstein, & Gray-Donald, 2011).

Sex, race, and socioeconomic factors. Physical function decline was reported to be linked with being a woman, being in different ethnic groups, and lower socioeconomic status. Studies have shown that compared to men, women had a higher prevalence of physical function issues (Dunlop, Hughes, & Manheim, 1997; Graciani, Banegas, López-García, & Rodríguez-Artalejo, 2004). Furthermore, a higher prevalence of physical function declines was found in both older African and Hispanic Americans when compared with White Americans (Kelly-Moore & Ferraro 2004). Compared to Singaporean Chinese, Indians and Malays living in Singapore had a higher risk of disability (Ng, Niti, Chiam, & Kua, 2006). For peoples in different socioeconomic groups, those with lower levels of education were more likely to have a higher prevalence of physical function decline in adults at all ages (Lafortune & Balestat, 2007).

Lifestyle behavior and injury factors. Less physical activity and prolonged sedentary time periods were evidenced to be strongly associated with physical function decline due to that such behavior would result in reduced muscle bulk and function leading to potential overall physical function decline (O'Caoimh et al., 2014; Seguin et al., 2012). Previous evidence has shown that smoking and heavy alcohol consumption were associated with physical function decline (Tas, Verhagen, Bierma-Zeinstra, Odding, & Koes, 2007). Meanwhile, foot problems and the number of medications taken were predicted 76% of physical function decline accurately using a decision tree method (Sibbritt, Byles, & Regan, 2007). Studies have shown that several

injuries have impact on physical function, such as lung injuries (Bienvenu et al., 2012), traumatic brain injuries (Safaz, Alaca, Yasar, Tok, & Yilmaz, 2008), and low back injuries (Mayer et al., 1987). In addition, the presence of pain was also related to physical function decline (Duong, Kerns, Towle, & Reid, 2005).

Health-related factors. As the population in the United States ages, the number of persons with chronic disease rapidly increases. Increasing evidence suggests people with chronic diseases, such as diabetes, hypertension, dyslipidemia, heart disease, and cancer, are at higher risk for functional decline (Bayliss, Bayliss, Ware, & Steiner, 2004). Though not all diseases result in physical function decline, stroke, neurological diseases, diabetes, heart disease, depression, arthritis, and musculoskeletal diseases all have strong effects on physical function (Avlund, 2004). Approximately 25% of adults with chronic illness have some limitations in their daily activities, and the prevalence of disability is increasing with the growing prevalence of people with chronic conditions (Anderson, 2010).

Physiological, sensory and cognitive factors. In addition to health-related factors, other physiological, sensory, and cognitive factors can contribute the development of physical function decline. Studies showed that individuals with visual impairment and cognitive impairment are more likely having a high risk of disability (Whitson et al., 2007) and the combination of both hearing and vision impairments has an immediate impact on physical function more than every single impairment (Lin et al., 2004). Meanwhile, physical function status was found to be negatively influenced by the onset of depression in community-dwelling older adults (Russo et al., 2007). One study found depression in older adults might increase the risk for disability onset, which can be partially explained by reduced physical activity and social activities (Penninx, Leveille, Ferrucci, Van Eijk, & Guralnik, 1999).

Aging factor. Aging is also a factor linked to physical function decline (Short et al., 2005). The world's aging population is increasing quickly. The 65 yr. or older population represented 14.5% of the U.S. population in 2014 (Ortman, Velkoff, & Hogan, 2014). According to aging statistics from the Administration on Aging (Mather, Jacobsen, & Pollard, 2015), by 2060, there will be about 98 million older adults in the United States, more than twice the 2014 number. Many health issues related to aging are becoming critical. Studies have shown that the aging process is paired with diminished physical fitness (such as strength, endurance, agility, and flexibility), which then leads to limitations in daily life activities and normal functioning of the elderly (Riebe et al., 2009; Tuna, Edeer, Malkoc, & Aksakoglu, 2009). Age-related declines in muscle mass and muscular strength are well established and documented (Thompson, 2007). The aging process could lead to 30-40% reduction in muscular strength (Stamford, 1988). There are several aspects to the reasons that can explain age-related muscle changes. The gradual loss of muscle fiber could cause changes in muscle strength and muscle function with aging (Lang et al., 2010). Additionally, the aging process could contribute to a higher frequency of fat cells in muscle tissue (Newman et al., 2003).

Physical Function Decline, Disability, and Health

Several conceptual models have been determined useful for modeling the progression of physical function deficiency to disability. According to a well-known description of disability (Nagi, 1991), disability is defined as:

Disability is a limitation in performing socially defined roles and tasks expected of an individual within a sociocultural and physical environment. The term disablement refers to the various impact of chronic and acute conditions on the functioning of specific body

systems, on basic human performance, and on people's functioning in necessary, usual, expected, and personally desired roles in society. (p. 315)

Based on this definition, the theoretical pathway from disease to disability is from pathology to physical impairment, to functional limitation, and then to disability. According to this pathway, the pathology is a referring medical disease, injury, or other health conditions. Impairment is the consequence of disease. Functional limitations are referring to physical function decline in daily life performance. Disability is also defined as functional limitations from a social perspective viewpoint. From this theoretical pathway, it is clear that physical function status is a key part of the pathway from diseases to disability.

In 1980, another theoretical framework for the pathway of disability was proposed by the World Health Organization (WHO) (1980). Then this framework was modified by WHO and was named the International Classification of Functioning (ICF), Disability and Health. In this modified framework, a new part entitled functioning and disability was added, which was composed of body functions and body structures, activities and participation. In addition, environmental factors and personal factors were also stressed in this new disability model. This model, illustrated in Figure 1, shows as people age, an increasing cap in functional capacity decline is developed due to lifestyle and environmental factors, which lead to different stages in life to reach the "disability threshold".

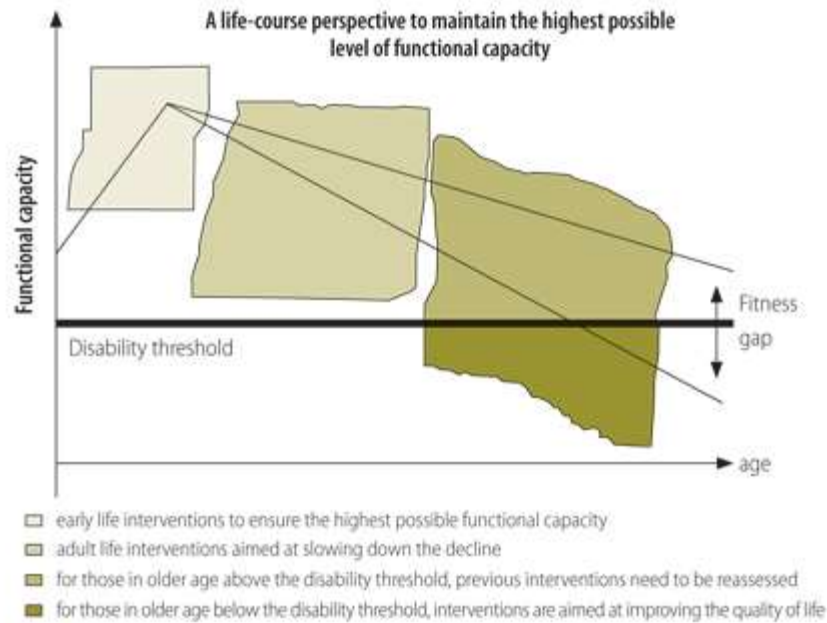


Figure 1. A life-course perspective to maintain the highest possible level of functional capacity (Peeters, Dobson, Deeg, & Brown, 2013)

In addition, Verbrugge and Jette (1994) extended Nagi's definition of disability by expanding dimensions of disability and including other factors like sociocultural and personal elements with key physical factors. A term "preclinical disability" (Fried, Herdman, Kuhn, Rubin, & Turano, 1991) was identified as a transitional stage between impairment and disability, which parallels functional limitation. Furthermore, as the severity of most chronic diseases increases over time resulting in physical function decline which can lead to elevated risks of disability, and the causal pathway from a chronic disease to the onset of disability was confounded by varying disease severity (Rozzini, Bianchetti, & Trabucchi, 1998).

Physical function status is also an essential health indicator among people with chronic diseases. For example, in a systematic review study, Stuck et al. (1999) found that increased risk of functional decline among community-living older people was associated with cognitive

impairment, depression, comorbidity, increased and decreased body mass index (BMI), lower extremity functional limitation, low frequency of social contacts, low level of physical activity, poor self-perceived health, smoking, and vision impairment. Additionally, studies also found a significant association between physical function decline with other outcomes such as level of dependency, nursing home admission, falling, and hospitalization (Painter, Stewart, & Carey, 1999).

Traditional Physical Function Assessments in Physical/Occupational Therapy

Physical function assessment, a complicated and multifaceted assessment, is composed of different types such as self-report questionnaires, performances measures for specific tasks, and vigorous laboratory measures. Each measurement method can provide information on physical function status and daily life quality. Physical function measures always involve several components of physical fitness like muscular strength, flexibility, and balance.

Level of physical functioning can be assessed using performance-based measures in clinical research (Curb et al., 2006; Wang, Larson, Bowen, & van Belle, 2006). Despite there being performance-based measures, physical function questionnaires (Figure 2) based on daily life activities were the most common assessment employed in population-based surveillance and epidemiological studies to measure physical functioning ability in daily life (Jenkinson, Peto, Fitzpatrick, Greenhall, & Hyman, 1995; Sternfeld, Ngo, Satariano, & Tager, 2002). Findings reveal that for a sample of patients after fracturing a hip, validity, sensitivity, and responsiveness of physical function questionnaires are comparable to performance-based measures (Latham et al., 2008).

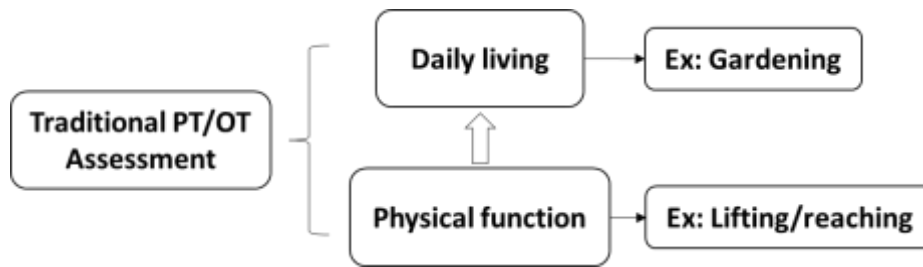


Figure 2. Traditional PT/OT assessment using questionnaire

Self-report questionnaire measures on physical function were based on subject-completed and self-perception of mobility status and daily activity difficulties. Commonly included items in physical function questionnaires are about performance difficulties, restrictions, and need for assistance linked with specific functional activity (Latham et al., 2008). Various common questionnaires have been used to measure physical function decline, such as the Short Form Health Survey (SF-36), National Health Interview Survey (NHI), physical function items in the National Health and Nutrition Examination Survey (NHANES), and the previously mentioned physical function item bank in PROMIS. One study reported that in health care and rehabilitation, self-reported questionnaire measures could provide valuable information about symptoms and function which were not available in performance-based measures of physical function (Cella, Gershon, Lai, & Choi, 2007).

There are several advantages of performance-based measures including reproducibility and less sensitivity to external influences like cognition, language, and culture (Guralnik, Branch, Cummings, & Curb, 1989). Even though performance-based measures of physical function could provide more information on sensitivity and specificity compared to self-report questionnaires (Brach, VanSwearingen, Newman, & Kriska, 2002), numerous studies have shown that the physical function questionnaire measure also has been demonstrated to have a

moderate to high association with objective performance-based tests (Latham et al., 2008; van Den Brink et al., 2003), and it is comparable on psychometric properties of self-report and performance-based measures (Hoeymans, Wouters, Feskens, van den Bos, & Kromhout, 1997; Latham et al., 2008). To identify early and mild deficits in physical function, the self-report measure was recommended by researchers (Brach, VanSwearingen, Newman, & Kriska, 2002).

Physical Fitness

Physical fitness is defined as “a physical state of well-being that allows people to perform daily activities with vigor, reduce their risk of health problems related to lack of exercise, and establish a fitness base for participation in a variety of physical activities.” (McSwegin, Pemberton, Petray, & Going, 1989, p. 11). This definition of physical fitness evolved out of older definitions, such as “the individual’s functional capacity for a task”, “the degree of the ability to execute a specific physical task under specific ambient conditions”, “the ability to carry out daily tasks with vigor and alertness, without undue fatigue, and with ample energy to enjoy leisure time pursuits and to meet unforeseen emergencies”, and “functional capacity of individuals to perform certain kinds of tasks requiring muscular activity” (Pate, 1988, p. 175). To distinguish from physical function, physical fitness was also defined as a set of attributes that people have or achieve relating to their ability to perform physical activity (U.S. Department of Health and Human Services, 1996). This study chose the definition from the U.S. Department of Health and Human Services (1996) to define physical fitness as a set of attributes that people have or achieve relating to their ability to perform physical activity. This definition described the relationship between physical fitness and physical function in that physical fitness is a set of attributes such as muscle strength and flexibility, while physical function is the function of these attributes to do physical activity.

Physical Fitness Components

Physical fitness components and measurements have changed over time, from primarily performance-related fitness of motor and strength to greater focus on health-related fitness aspects, such as cardiorespiratory endurance, muscular endurance, muscular strength, body composition, and flexibility (Caspersen, Powell, & Christenson, 1985; Malina, 2001; McSwegin, Pemberton, Petray, & Going, 1989). When physical fitness was measured, physical function capacity for daily physical activity was also tested (Ortega, Ruiz, Castillo, & Sjöström, 2008). As the definition of physical fitness changed, the components of physical fitness were modified several times according to whatever was the new focus on physical fitness at the time. Traditionally, physical fitness had two kinds of components: health-related physical fitness and skill-related physical fitness. In which, health-related physical fitness consisted of cardiorespiratory endurance (aerobic endurance), muscle strength, flexibility, and body composition. Skill-related physical fitness consisted of balance, agility, coordination, and power. Figure 3 illustrates several common physical fitness traits including aerobic endurance, muscle strength, flexibility, balance, and coordination.

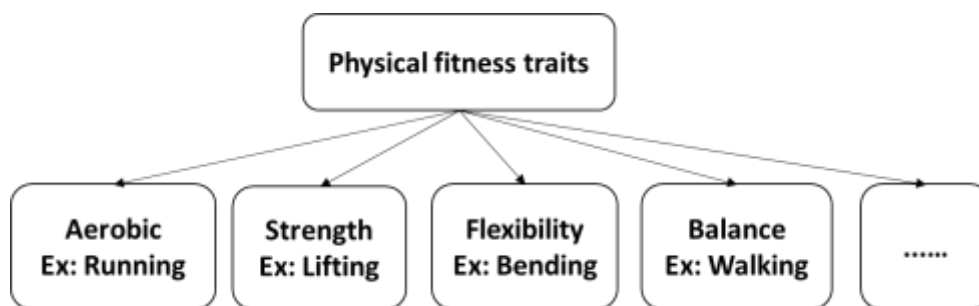


Figure 3. Physical fitness components

Cardiorespiratory endurance. Cardiorespiratory endurance, also known as “aerobic capacity”, is the ability to exercise the entire body for a long time without stopping (Bouchard, Shephard, & Stephens, 1993). As a key component of health-related physical fitness, aerobic capacity is also defined by the highest amount of oxygen consumed during maximal exercises in activities. For example, running a marathon and high-intensity circuit training are common examples of activities needing cardiorespiratory endurance, which is typically indicated using measured or estimated maximum oxygen consumption (VO_{2max}) (Castillo Garzón, Ruiz, Ortega Porcel, & Gutiérrez, 2006a). Cardiorespiratory fitness has been treated as an objective and reproducible measure reflecting the functional status of recent physical activity habits, disease status, and genetics (Haskell et al., 1992). Previous studies demonstrated that lower aerobic capacity is related with higher risk of all-cause and cardiovascular disease mortality in younger and middle-aged men regardless of their health status (Barlow, Kohl III, Gibbons, & Blair, 1995; Church et al., 2004). Additionally, cardiorespiratory fitness has been identified to be linked with the preservation of cognitive function in healthy older adults and high cardiorespiratory fitness could help against cognitive dysfunction in older people (Barnes, Yaffe, Satariano, & Tager, 2003).

Muscular strength. Muscular strength is the ability to produce force using muscles. Muscular strength, which is also defined as a balanced, healthy functioning of the musculoskeletal system, is supported by muscle groups that can generate force or torque (Bangsbo, 2003). For example, muscular strength is the main ability required when performing squats and pull-ups. Muscular strength is an important part of physical fitness required to maintain normal physical function. Studies suggested that muscle function including strength, power, and endurance, which is related to but also is independent of aerobic fitness, might lead to

increased physical function and longevity (Blair et al., 1996). Muscular strength is treated as a critical component in maintaining physical function. Decreasing muscular strength with aging is associated with functional impairment, disability, falls, and loss of independence for older adults (Evans & Campbell, 1993; Rantanen, 2003).

Flexibility. Flexibility is defined as "the intrinsic property of body tissues, which determines the range of motion achievable without injury at a joint or group of joints." (Holt, Holt, & Pelham, 1995, p. 172). Flexibility is a very important health-related component in the individuals' body function. For example, bending and stretching the body all require flexibility. It has been documented that flexibility declines 20-50% among adults from age 30 – 70 years depending on the joint examined (Chapman, de Vries, & Swezey, 1972). As age increases, flexibility decreases related to muscle disuse and soft tissue restraints (Mazzeo et al., 1998). This flexibility trend was verified by the associations between flexibility losses with physical function decline and other health issues for older people who cannot perform daily life activity smoothly (Bergström et al., 1985; Gehlsen & Whaley, 1990). Therefore, maintaining flexibility in aging adults is important to protect them from possible disability.

Body composition. Body composition is defined by the percentage of body fat, muscle, water, and bone mass in the human body. It is usually referring to the percentage of body fat in when discussed in regards to fitness. Obesity, i.e., too much body fat, is a common risk factor for some chronic diseases, such as heart diseases, cancer, and diabetes. Body fat was treated as a standard method to assess obesity status. High body fat was found to be linked with higher risk for metabolic syndrome among older adults (Goodpaster et al., 2005). Regular physical activity paired with a healthy diet could help reduce body fat, and BMI. Studies also evidenced that preventing excessive accumulation of body fat and a high BMI could reduce the possibility of

physical functional limitations in older people (Davison, Ford, Cogswell, & Dietz, 2002).

Balance. Balance is defined by the ability to control body positions while standing still or moving. Numerous studies documented that low levels of balance are an important risk factor for loss of physical function and the onset of falls in older adults (Buchner & Wagner, 1992; Robbins et al., 1989). One study reported that short-term balance training could improve overall balance measures meaningfully by restoring performance to a level of an individual 3-10 years younger (Hong, Li, & Robinson, 2000).

Agility. Agility is defined by the ability to stop, start, and change directions quickly (Chelladurai, 1976; Parsons & Jones, 1998). In general, changing directions might be necessary for pursuing, evading, or reacting to an object. Traditionally, agility was assessed by timing individuals' running through a series of obstacles or cones at a determined distance. One study has found that agility training had a significant effect on reduction of fall risk and improved postural stability for older people (Liu-Ambrose, Khan, Eng, Heinonen, & McKay, 2005). The possible reason could be that higher agility skills help older people to maintain quicker reaction times to prevent possible falls. Regular agility training was also found to be able to improve health-related quality of life in community-dwelling older women with low bone mass (Liu-Ambrose et al., 2005).

Coordination. Coordination is defined by making movements work together smoothly. For example, traversing ropes and crossing obstacles demand coordination ability. Coordination can be increased by performing physical activities. The ability of coordination is important in daily life since it has been well-documented that coordination ability is associated with reduced risks of falling and increased postural control (Wong, Lin, Chou, Tang, & Wong, 2001). One

study observed the relationship between coordination training and increased activation in the visual-spatial network, when the coordination training was developed to improve fine and gross-motor body coordination including hand-eye coordination and leg-arm coordination (Voelcker-Rehage, Godde, & Staudinger, 2011).

Power. Power is defined as the ability to use muscle strength for a short time. For example, most jumping exercises are related to power fitness. To increase power capacity, individuals need to increase the force-producing ability of muscles. Existing evidence showed that poor lower-limb explosive power might be a predictor of future falls and women who fall had 24% less power than women who did not fall (Skelton, Kennedy, & Rutherford, 2002).

Physical Fitness and Health

Physical fitness itself has independently been found to be correlated with the health status of adults. For example, the lack of muscular strength is an important factor in the institutionalization of frail older adults (King, 1991). Low levels of physical fitness are demonstrated to be associated with an increased risk of all-causes of mortality and cardiovascular diseases (Blair et al., 1995). For example, studies have shown that VO_{2max} is the key measurement of aerobic capacity, and it is the essential predictor of all-cause mortality for people with cardiovascular disease (Carnethon et al., 2003) and at any age (Myers et al., 2002). VO_{2max} is also related to metabolic syndrome (Bertoli et al., 2003). Both muscular strength and cardiorespiratory fitness have been demonstrated their associations with metabolic syndrome prevalence (Jurca et al., 2004). Muscular strength was linked to being all-cause mortality in both men and women, independent of cardiorespiratory fitness levels (Jurca et al., 2004) and people with type 2 diabetes were found to have common muscle weakness in the ankle and knee

(Andersen, Nielsen, Mogensen, & Jakobsen, 2004).

Studies demonstrated that age-related muscle weakness and declined aerobic capacity lead to multiple metabolic disorders and reduced physical performance (Balagopal, Rooyackers, Adey, Ades, & Nair, 1997; Rooyackers, Adey, Ades, & Nair, 1996). Among these, declined muscle function is also related to reduced aerobic capacity (Short et al., 2005). Fitness training has robust but selective benefits for cognition, with the largest fitness-induced benefits occurring for executive-control processes (Colcombe & Kramer, 2003). Therefore, physical fitness is considered one of essential health markers and predictor for cardiovascular disease and all causes of morbidity (Ortega, Ruiz, Castillo, & Sjöström, 2008).

Physical Function Decline and Physical Fitness

The U.S. Department of Health and Human Services (1996) defines physical fitness as a set of attributes that people have or achieve relating to their ability to perform physical activity. This definition describes the relationship between physical fitness and physical function that physical fitness is a set of attributes to support physical function capacity.

According to the above definitions of physical function and physical fitness, physical function is more about abilities to do daily living activities, while physical fitness is more about people's physical parameters or attributes relating with abilities to do activities of daily living. Therefore, based on these definitions and the literature reviews that the ability to perform daily activities or tasks is determined by a threshold of muscular strength and endurance (Fukagawa, Brown, Sinacore, & Host, 1995; Schwartz & Evans, 1995), physical fitness is the underlying key to support people's physical function, and lacking physical fitness could limit people's physical function (Brill, Macera, Davis, Blair, & Gordon, 2000).

Even though there are numerous widely used physical function assessment tools to measure function status, most researches are only focusing on physical function itself. The underlying physical reasons such as physical fitness deficiency causing physical function decline should also be emphasized. Physical fitness is the capacity to perform a physical activity. It is referring to the components of physical traits such as aerobic endurance, muscle strength, speed, agility, coordination, and flexibility. According to the above definition, physical fitness also can be considered as an integrated assessment of body structures and functions. Therefore, individuals who were physical unfit should have low function and body structure status (Castillo-Garzon, Ruiz, Ortega, & Gutierrez-Sainz, 2006b).

Some important prospective studies have shown that muscle mass decline is linked to the development of physical function limitations and disability among older adults (McDermott et al., 2004; Visser, Deeg, Lips, Harris, & Bouter, 2000). Physical fitness programs are known to be beneficial for older adults' physical and mental well-being, social functioning, carrying out of physical and emotional roles, general health, and increasing level of vitality (Dorgo, Robinson, & Bader, 2009). Consequently, to preserve the function and independence of older adults, understanding the contribution of physical fitness components to functional performance can promote the constructive exercise interventions (Singh, Paw, Bosscher, & Van Mechelen, 2006).

According to literature reviews, several components of physical fitness can predict physical functional capacity. For example, a study shows that knee extensor strength and aerobic capacity predicted the timed performance of daily tasks in adults with Down syndrome (Cowley et al., 2010). Muscle quality, aerobic fitness, and fat mass are significant predictors of lower extremity physical function in community-dwelling older adults (Misic, Rosengren, Woods, & Evans, 2007). In addition, reduced muscular strength was associated with increased difficulty in

doing daily tasks (Landers, Hunter, Wetzstein, Bamman, & Weinsier, 2011). Sometimes, researchers combined physical fitness and physical function into one item called functional fitness, which is generally defined as the ability to perform daily living activities without difficulty (Rikli & Jones, 2013).

Researchers from California State University, Fullerton, developed a performance-based functional fitness test for older adults called the Senior Fitness Test (Rikli & Jones, 2001). The test is based on a functional fitness framework, which indicated the physiologic parameters associated with functions required for basic and advanced everyday activities. Among those, physiologic parameters are traditional physical fitness components such as muscular strength, aerobic endurance, flexibility, and so on. A unique feature of the test is that its physical fitness assessments are based on physical function movement tasks, which is similar to that of traditional items from physical function questionnaires.

Physical Activity, Fitness and Function

Physical activity is defined as any body movements produced by skeletal muscles that result in energy expenditure. Physical activity, as a normal life necessary aspect, has energy expenditure varying from low to high, and physical activity is positively correlated with physical fitness status (Caspersen, Powell, & Christenson, 1985). Since physical activity is always associated with physical fitness, physical activity has been treated as the main approach to improve physical fitness.

Physical Activity and Fitness

Based on existing studies (Bouchard, Shephard, & Stephens, 1993; Caspersen, Powell, & Christenson, 1985), there is no doubt that physical activity is the main contributor to physical

fitness (Figure 4). Physical fitness could be ultimately improved by regular physical activity. The amount and rate of this improvement will differ for people with varying health status. Physical activity has demonstrated its positive benefits for both health and physical fitness (Corbin & Pangrazi, 1993). One study reported that aerobic exercise could prevent age-associated cardiovascular disease (DeSouza et al., 2000).

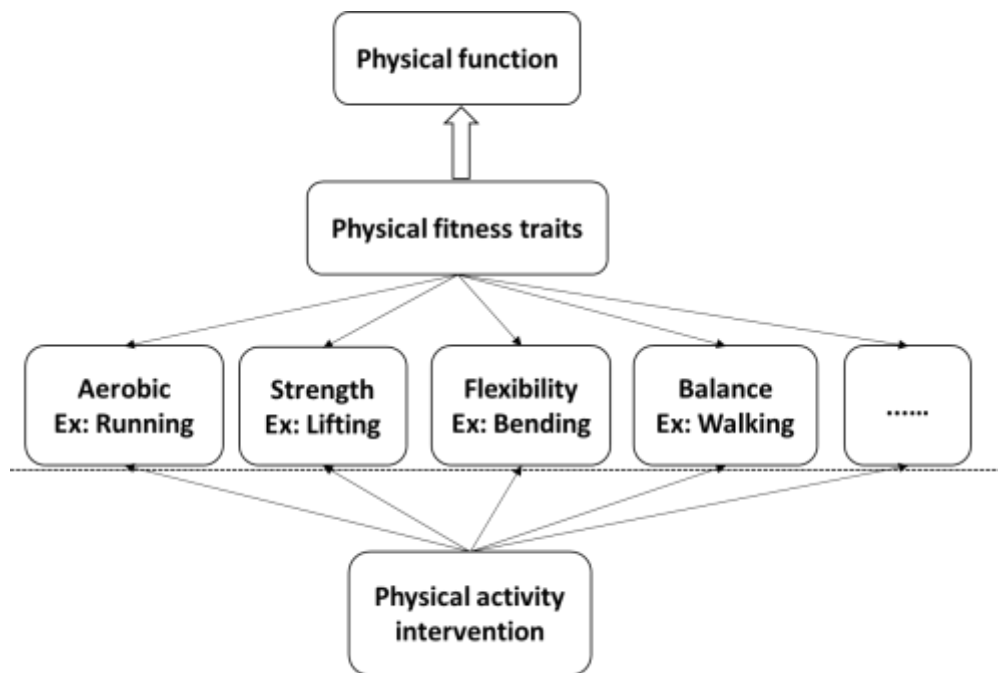


Figure 4. The relationship between physical activity and physical fitness

Physical Activity and Function

Different types of physical activity and exercise training were found to have effects on physical function. These effects varied by different physical activity intensities and population groups. Based on a systematic review of 121 trails and 6,700 participants, a study showed that progressive resistance strength training exercises could be used to improve older adults' physical function status which includes muscle weakness, physical disability, and function declines such

as balance, gait speed, and walking time (Liu & Latham, 2009). Specifically, progressive resistance strength training has a statistically significant effect on physical function promotion (Liu & Latham, 2009). It also has low to moderate effect on reducing impairments caused by physical function limitations (Liu & Latham, 2009). What is more, preliminary evidence showed that progressive resistance strength training could be applied to decrease osteoarthritis pain and prevent falls in older adults (Brosseau, MacLeay, Welch, Tugwell, & Wells, 2003; Gillespie et al., 2003).

Yorston, Kolt, & Rosenkranz (2012) reported that higher levels of daily physical activity were linked to better physical function in adults over 45-years old and the association is significant and clearer when physically active adults are compared with habitual sedentary counterparts. Promoted physical activity was found to be associated with improved physical function after a 4-month community intervention that included educator-led chair exercises, promotion of walking, pedometer use, and recording of daily steps (Fitzpatrick et al., 2008). To improve regular physical activity amounts in daily life, avoiding obesity in older adults is also important to effectively prevent and slow down the loss of physical function (Riebe et al., 2009). An active lifestyle could help adults with physical function limitations to live healthier and longer (Balboa-Castillo et al., 2011). According to the above literature review, physical function status might to be improved by an appropriate physical activity intervention regardless of differing health situations.

Psychometric Foundations of Physical Function Measurement

Since physical function in PT and OT was commonly measured using questionnaires regarding daily life activities, several psychometric analysis methods for questionnaire results are

introduced in the following paragraphs. A common physical function analysis method is to add all item responses together to obtain the total score. This practice is called the classical test theory. To overcome some limitations of using the total score in CTT, the item response theory based on test construction was also employed to estimate individuals' physical functioning ability. Then computerized adaptive testing based on item response theory was introduced in physical function measurements to tailor the test length, individualize test and provide uniformly precise scores for different examinees.

Classical Test Theory

Allen and Yen (1979) comprehensively introduced CTT in their seminal textbook *"Introduction to Measurement Theory"*. In the framework of CTT, the total score of a test is usually reported as the most common examinee scoring strategy. Total scores of the physical function questionnaires, which were constructed based on classical testing theory, have been widely used in most studies to estimate the level of individuals' physical function (Bayliss, Bayliss, Ware, & Steiner, 2004; Kington & Smith, 1997). For example, Idler, Russell, & Davis (2000) obtained the amount of difficulty in physical function activities by creating a summary score to estimate relative hazards for mortality and functional limitations. Total score of self-report physical function was also implemented to investigate its relationship with inflammatory markers (Penninx et al., 2004).

The total score of the examinees can be determined by difficulty index of items in the test, while the item difficulty index only depends on the level of the examinees' ability and the person statistics and item statistics are sample dependent. Therefore, using total score has several limitations: (a) they are not uniformly precise scores since participants' ability could be

overestimated or underestimated only using total scores (Zhu, 1996); (b) participants' characteristics and questionnaires' characteristics cannot be separated (Hambleton, Swaminathan, & Rogers, 1991); (c) standard error of measurement is assumed to be the same for all participants using total score (Hambleton, Swaminathan, & Rogers, 1991); (d) problems of validity and reliability exist in the process of estimation of an instrument (Zhu, 1996); and (e) total score estimations from fixed long tests need more time and facilities.

Item Response Theory

To overcome the limitations of using the total score in CTT, the IRT based on test construction was employed to estimate individuals' physical functioning ability (DeMars, 2010; Embretson & Reise, 2013; Fan, 1998). IRT has been widely used in educational testing. Relying on the probability of correct responses, probability models in IRT could estimate the parameters of the specific item and examinee. Regarding different response scales, IRT estimation models are divided into several categories. For example, for the dichotomous response, Rasch model, one-parameter logistic model, two-parameter logistic model, and the three-parameter logistic model are current common IRT models (Zheng, 2014).

Regarding polytomous response types such as Likert Scales or multiple choices, several probability models can be applied to estimate item parameters and examinee's ability: Graded Response Model, Partial Credit Model, Rating Scale Model, and Nominal Response Model. Most of these models are constructed from the above dichotomous response models. Overall, IRT offers more information about the items and great flexibility in scoring and scaling the assessed traits compared to CTT.

A physical function item bank was developed and calibrated based on IRT (Fries, Bruce,

& Cella, 2005; Rose et al., 2014). To measure physical function more accurately, IRT has been successfully applied in the physical function items from the PROMIS data set (Hays, Liu, Spritzer, & Cella, 2007; Hung, Clegg, Greene, & Saltzman, 2011) and clinic patients in Wisconsin (McHorney & Cohen, 2000). An existing study also found that using IRT-based items could provide greater responsiveness and precision across a wider range of physical function, which helps in reducing sample size requirements (Fries, Krishnan, Rose, Lingala, & Bruce, 2011).

Computerized Adaptive Testing

Though IRT has a lot of advantages compared to CTT, the long length of tests based on IRT still limits its wide application in physical function measurement. Thus, computerized adjustment testing (CAT), a modern testing mode, not only is able to tailor test length but also provides uniformly precise scores for different examinees. Therefore, CAT has become regarded as a comprehensive and systematic assessment of physical function with the potential to improve the precision and efficiency of traditional disability evaluation process (McDonough et al., 2013). To address limitations of lacking uniform precision and long length required of tests based on IRT, the Department of Medical Social Sciences at Northwestern University, supported by National Institutes of Health (NIH), designed a CAT system for participants to measure their individualized physical function limitations (Bruce et al., 2009; PROMIS, 2016).

Limitations of IRT and CAT Applications

Both IRT and CAT applications provided a single ability score estimation, but it did not provide more specific diagnostic information relevant to why participants' ability differed with each other and what is the underlying reason for this difference. Therefore, while the latest measurement model and methods (e.g., IRT and CAT) have been applied to physical function

measurement, two major gaps still exist: (a) the underlying physical fitness traits of commonly used physical function assessments has not been identified and documented, and (b) the association between a person's physical fitness profile and chronic diseases has not been well established. There is one existing study that simply classified physical function items from Health and Retirement Study to different domains (mobility limitation, large muscle function limitation, activities of daily living limitation, gross motor function limitation, and fine motor function limitation) (An & Shi, 2015), whereas the fine-grained level information on physical fitness were still missed in this classification. Both Cress, Buchner, Questad, Esselman, & Schwartz (1996) and Hearty, Schenkman, Kohrt, & Cress (2007) have developed continuous scales for physical functional performance and correlated it with physical function questionnaires by using a subscale score analysis. However, the subscale score analysis was not based on a fundamental diagnostic theory.

Therefore, the underlying physical fitness aspects of physical function, such as muscular strength, flexibility, aerobic endurance, balance and fine motor skill, are not well known. At the same time, the association between chronic disease and underlying physical fitness profiles remains inconclusive. As a result, rich patterns or profile information embedded in the physical functional measures are often overlooked. To diagnose what is the possible underlying reason for physical function limitation, more physical fitness diagnosis information should be provided in the diagnostic analysis.

Diagnostic Assessment to Fill the Gaps

Diagnostic assessment, as a modern psychometric method, has been widely used in educational fields. To illustrate how diagnostic assessment can be utilized in physical function measurement, background information about diagnostic models, examples of current CDM

applications, and model constructions are introduced.

About Diagnosis Models

In educational assessment, researchers in the past designed various models aiming for measurements on the probability of mastery or nonmastery of predefined skills or attributes in one test. Since these models were usually applied in cognitive measurement, these models were called CDM. Each individual's mastery status on skills usually expressed by profiles of mastery or nonmastery (Henson, Templin, & Willse, 2009), which can be estimated by using cognitive diagnosis models.

Compared with CTT and IRT, CDM provides information about the possible underlying reasons for why participants did not perform well based on skill mastery or nonmastery analyses. When CTT or unidimensional IRT was applied, a continuous measure of ability was estimated, whereas this continuous measure of ability can only provide an overall estimation of participants' abilities. Additional information about what reasons led to participants' different performances are ignored in traditional measurement theories. Fortunately, CDM provide this diagnostic information about mastery or nonmastery of skills so that individuals could get benefits from these diagnostic feedbacks from CDM.

Accordingly, the CDM theory was based on the set of predefined skills or attributes for each item from a test. Therefore, estimations for each individual's mastery or not of skills will be largely influenced by the skills themselves. So before any applications of CDM, usually the assumptions of how the skills will influence the participants' performance need to be set accordingly. In addition, the output resulting from CDM is the mastery profile for predefined attributes which are defined by the probability of a correct response. There is a primary

assumption of CDM that all individuals who mastered the same set of required attributes for given items in a test would have the same probability to respond to an item correctly (Henson, Templin, & Willse, 2009).

The Existing Applications of CDM

Numerous previous studies exist about CDM applications in educational and psychological areas. For example, math exams can use CDM to diagnose specific skills mastery (de la Torre & Douglas, 2004). CDM has been used in language assessment, in which reasonable sets of dichotomous attributes according to items were verified using CDM (Jang, 2005). Interestingly, CDM has also been applied in other social science areas. For example, a study from Templin and Henson (2006) used CDM to evaluate pathological gambling attributes.

Q-matrix Construction

To use CDM in diagnosing participants' underlying attribute profiles, the first step to apply CDM is setting the relationship between required attributes and each item. To map this relationship, a known way is to build a particular item-by-skill table which is also called Q-matrix (Tatsuoka, 1983). In this Q-matrix, each item is defined to corresponding attributes required for participants in order to answer this item correctly, which is dependent on maybe one or more attributes (DeCarlo, 2010; Li & Suen, 2013). Traditional dichotomous Q-matrix is illustrated in Table 1. The value in a cell between one item and one attribute could be 0 or 1. Zero means that this attribute is not a required attribute to answer the corresponding item correctly, whereas one means that this attribute is a required attribute to answer the corresponding item correctly. Some other types of Q-matrix can also be constructed based on polytomous values. In

other words, not only 0 or 1 but also other ordered categorical scales can be assigned to the relationship between items and attributes.

Table 1

An Example of Q-matrix

Item	Attribute 1	Attribute 2	Attribute 3	...
Item 1	1	0	1	...
Item 2	0	1	0	...
Item 3	0	0	1	...
...	...	...	...	...

Usually, Q-matrix is built based on the following procedure according to Sawaki, Kim, & Gentile (2009): (a) develop an initial list of skills; (b) code each item based on what skills are required for each item to construct an initial Q-matrix; (c) analyze data using an appropriate CDM with the developed Q-matrix; and (d) modify the initial Q-matrix based on statistics for each attribute along with the theoretical importance of the skill. To obtain a well-defined Q-matrix, usually steps 3 and 4 need to be repeated (Li & Suen, 2013).

Models in CDM

According to the traditional classification framework of models in CDM, there are two sorts of distinctive models: compensatory models and non-compensatory models. Non-compensatory models can further be divided into two differing models which are conjunctive and disjunctive models. Different models have various specific assumptions of how participants' performance will be influenced by predefined skills (Henson, Templin, & Willse, 2009).

Conjunctive models. For the conjunctive models in non-compensatory models, these models are usually used for situations that participants cannot “make up” for nonmastery of

attributes by mastery of other attributes (Henson, Templin, & Willse, 2009). In other words, under the assumption of conjunctive models in non-compensatory models, if the participant would like to perform well on one item, this participant needs to master all required attributes. Otherwise, if one attribute was not mastered by the participant, the probability of answering that item correctly will be reduced a lot. There are two well-known common conjunctive models, such as the Deterministic Input; Noisy “And” gate (DINA) (Haertel, 1989; Junker & Sijtsma; 2001) and the Reparameterized Unified Model (RUM) (Hartz, 2002).

Taking the DINA model for example, for each item, the DINA model splits participants involved in the test into two groups, those who have mastered all required attributes and those who have not mastered all required attributes for that item. Let X_{ij} denote the participant i 's response to the j th item and α_i denote the participant's latent attribute pattern which is going to be estimated, where $\alpha_i = (\alpha_{i1}, \alpha_{i2}, \dots, \alpha_{iK})$. Here K is the total attributes required for all item in the test. Each α_{ik} could be 0 or 1 for k from 1 to K . Then the ideal response pattern obtained under α_i can be expressed by the symbol ξ_{ij} . For participants who mastered all required attributes for that item, the value of ξ_{ij} will be 1, otherwise, it will be 0. For participant i and the item j , the value of ξ_{ij} can be represent by the following:

$$\xi_{ij} = \prod_{k=1}^K \alpha_{ik}^{q_{jk}}, \quad (1)$$

The DINA model has two parameters for items that are s_j and g_j . s_j is the probability of incorrectly answering an item when all required attributes have been mastered by the participant.

It is also called as slipping parameter. g_j is the probability of correctly responding to an item when all required attributes have not been mastered by the participant. It is also called a guessing parameter, where $g_j < (1 - s_j)$. The above two parameters can be represented by the probability:

$$\begin{aligned} s_j &= P(X_{ij}=0 | \xi_{ij}=1) \\ g_j &= P(X_{ij}=1 | \xi_{ij}=0) \end{aligned} \quad (2)$$

With the known j th item's parameters and ξ_{ij} , the probability of a correct response (also called item response function) can be expressed as:

$$P(X_{ij}=1 | \xi_{ij}) = (1 - s_j)^{\xi_{ij}} g_j^{1-\xi_{ij}}, \quad (3)$$

Disjunctive models. Disjunctive models that can be interchanged with compensatory models, are usually considered as the “opposite” of conjunctive models (George, Robitzsch, Kiefer, Groß, & Ünlü, 2016). In the disjunctive model, the probability of a correct response to one item depends not on whether the participant has mastered all required attributes or not, but depends on whether the participant has mastered any subset of the attributes. Specifically, one mastered most required attributes is anticipated to have a similar probability to answer the item correctly with one mastered all required attributes for that item. For example, a widely used common disjunctive model is the Deterministic Input; Noisy “Or” gate model (DINO) (Templin & Henson, 2006).

DINO model is very similar to the above DINA model since it also models the item response function based on the same two parameters that slipping s_j and guessing g_j , where

$g_j < (1 - s_j)$. The difference between DINA and DINO is that DINO defined a latent variable ω_{ij} instead of defining ξ_{ij} .

$$\omega_{ij} = 1 - \prod_{k=1}^K (1 - \alpha_{ik})^{q_{jk}}, \quad (4)$$

ω_{ij} is an indicator of whether the i th participant has mastered at least one of the required attributes for the j th item. Then ω_{ij} could be 1 which means the participant mastered one or more required attributes. It also could be 0 which means the participant did not master any of the required attributes. In this situation, the probability of a correct response (or item response function) is defined as:

$$P(X_{ij}=1|\omega_{ij}) = (1 - s_j)^{\omega_{ij}} g_j^{1-\omega_{ij}}, \quad (5)$$

Compensatory models. Compensatory models are defined that individuals can “make up” their attributes which they lack by having other mastered attributes. In other words, in the compensatory model framework, the conditional relationship between any attribute and the item response does not depend on whether the participant has mastered or not mastered the required attributes of that item. However, in the non-compensatory model, this conditional relationship depends on the mastery or nonmastery of required attributes of items. There are two widely used common compensatory models: General Diagnostic Model (GDM) (Davies, 2008) and a special case of the GDM called the compensatory RUM (Hartz, 2002).

For example, the compensatory RUM is defined as:

$$P(X_{ij}=1|\alpha) = \frac{\exp(\sum_{k=1}^K r_{jk}^* \alpha_{ik} q_{jk} - \pi_j^*)}{1 + \exp(\sum_{k=1}^K r_{jk}^* \alpha_{ik} q_{jk} - \pi_j^*)}, \quad (6)$$

where r_{jk}^* is the mastered attribute which is always > 0 . $-\pi_j^*$ is similar to a guessing parameter, which will determine the lowest probability.

Statement of the Problem

According to the above literature review, as people age, they are at risk of decline in physical function, and these declines can lead to disability and other health issues. Diagnosing the status of underlying traits that lead to these changes and declines could be crucial to prevent more serious consequences. Once diagnosed, compensatory and preventative strategies can be implemented such as effective exercise and physical activity programs. However, traditional physical function measurements have been limited to the physical function itself and ignored the physical fitness aspect. The ignored information of physical fitness is key to prevent physical function decline, which makes exercise prescription and intervention important yet difficult to do based on physical function results presently.

I believe that applying the latest diagnostic measurement models (Gierl, Alves, Roberts, & Gotzmann, 2009; Leighton & Gierl, 2007; Lutz, 2012) could help identifying underlying physical fitness traits from the commonly used physical function questionnaires, and detecting physical fitness profiles which can be used to link with health outcomes and chronic diseases. By obtaining physical fitness diagnostic results from physical function questionnaires, exercise interventions will become much easier to design individually. For example, if a person's physical function decline is due to a weakness in muscular strength and balance, corresponding exercises addressing those traits can be prescribed (as illustrated in Figure 5):

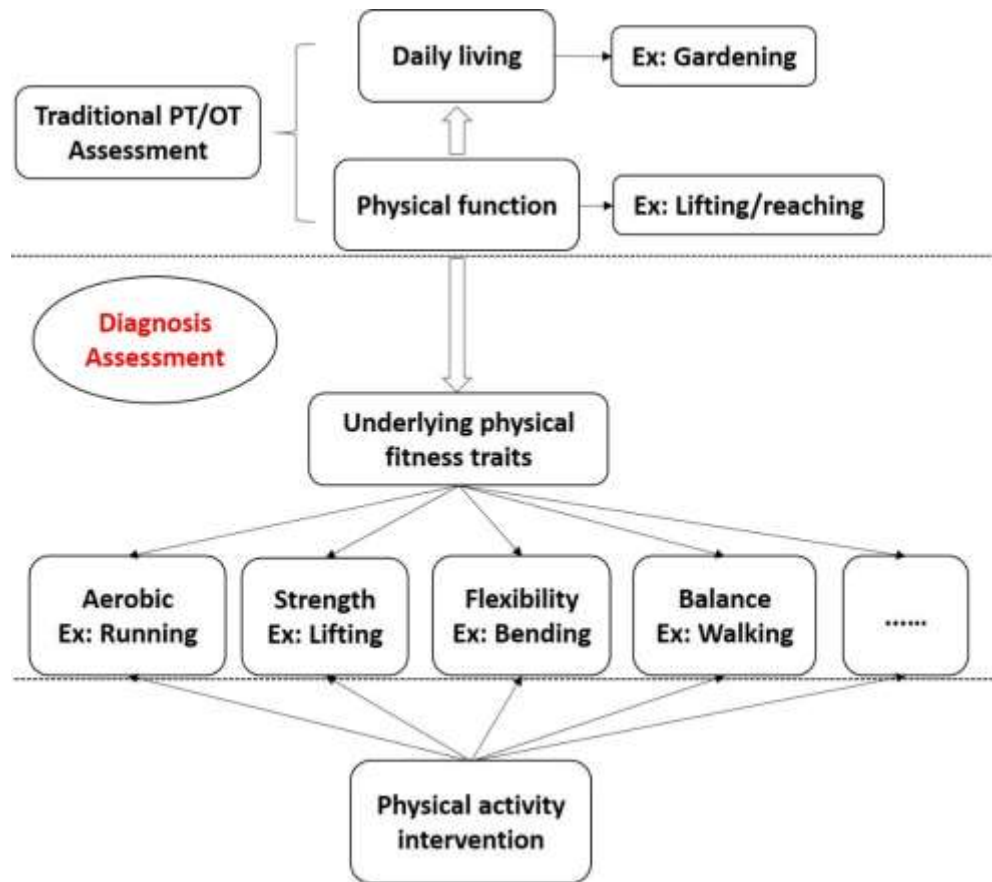


Figure 5. Flow chart for the background of this study

Purpose & Specific Aims

The main purpose of this study is to apply a diagnostic model that can help diagnose adults' status of physical fitness traits based on their physical function status. Simultaneously, this study can demonstrate the possibility of using diagnostic models in kinesiology. Upon the completion of this study, the best diagnostic model may be built and validated, which can be used in the future, for more people who have problems on physical function, to explore their body fitness issues. This unique diagnose information can be easily used in OT and PT for further physical activity intervention design. By applying the CDM to data from one U.S. national study and one Chinese Parkinson's disease study, the specific aims of this study are:

1. Identify the underlying physical fitness traits from a major self-reported physical functional assessment bank;
2. Derive individuals' physical fitness traits/profiles using the diagnostic model and diagnose individuals' physical strengths and weaknesses;
3. Examine the relationships between physical fitness traits and age/chronic diseases measures;
4. Validate the diagnostic model by comparing the diagnosed physical fitness trait statuses and performance-based physical fitness test scores.

CHAPTER 3: METHODS

This chapter describes the participants, data source, research procedures, and statistical analyses of this study, which is composed of two sub-studies. Study I was the development of a diagnostic model based on an U.S. dataset and Study II was to cross-validate the diagnostic model. Study I was designed to recruit experts to develop the Q-matrix from an existing physical function questionnaire so that corresponding diagnostic models could be tested, to estimate the prevalence of underlying physical fitness trait deficiencies, and to reveal the associations between chronic diseases and physical fitness trait deficiencies. Study II was designed to cross-validate the diagnostic model developed in Study I using a secondary dataset obtained from Chinese participants with Parkinson's disease.

Study I: Development of Diagnostic Model

Participants, Data Source, and Measures

In Study I, a group of experts was recruited for the diagnostic model development. Three experts in the areas of physical function and physical fitness were invited to develop the Q-matrix for the diagnostic model development. The inclusion criteria for experts was: (a) a Ph.D. degree in kinesiology or exercise science; and/or (b) research interests focused on physical activity/fitness, functional fitness, disability, or physical therapy. Potential experts were formally invited by emails and a meeting followed after a positive response.

To construct a Q-matrix linking physical fitness traits and physical function items before the diagnostic modeling, the participating experts rated each item of PROMIS physical function banks and linked it with potential underlying physical fitness traits.

The most appropriate diagnostic model was selected by applying several diagnostic models to an existing dataset called Patient-Reported Outcomes Measurement Information System. Then the prevalences of physical fitness traits among U.S. adults were analyzed, and the associations between underlying physical fitness traits and health outcomes were examined.

PROMIS. PROMIS was a NIH funded study to assess patient-reported outcomes measurement information. It is a set of person-centered measures that evaluates and monitors physical, mental, and social health in adults and children from both the general population and for individuals with chronic conditions (NIH, 2010). PROMIS Network investigators from six primary research sites measured and evaluated the dimensions of physical, mental, and social health (Bruce et al., 2009). All physical function items were calibrated based on an IRT graded response model (Rose et al., 2014) and re-scaled using scale-setting subsamples matching the marginal distributions of sex, age, race, and education level completed in the 2000 U.S. census (PROMIS, 2016). There were three physical function item banks (each one with 56 items) in the PROMIS dataset. However, only two item banks, physical function A (PFA) and physical function B (PFB), were administered to the same group of PROMIS participants. Therefore, all 112 items that make up the PFA and PFB banks were used in this study. Appendix A reports the item specifications.

PROMIS data were collected primarily by YouGovPolimetrix, a polling firm based in Palo Alto, CA (NIH, 2010). Among all 21,133 PROMIS participants, 942 participants answered all the physical function items in Bank A and B (112 items). This study included only those who answered all physical function items of Bank A & B in PROMIS Wave I study ($N = 942$, 51.17% women, 18-88 years old).

PROMIS Physical function questionnaire. Physical functioning status was measured

from answers to a series of items about self-reported difficulties in performing functional activities in daily life, such as carrying heavy objects, doing yard work, dressing, preparing meals, etc. Items covered upper, central, and lower extremity functions and instrumental activities of daily living. Respondents were asked whether they were able to perform the tasks “without any difficulty”, which was scored as “5”, “with a little difficulty = 4”, “with some difficulty = 3”, “with much difficulty = 2”, or “unable to do = 1”. During the item construction, all items were qualitatively evaluated by experts and participants (Bruce et al., 2009). In this study, all physical function responses were recoded as dichotomous to meet the requirements of diagnostic modeling (i.e., response of “without any difficulty” was recoded to “1” and other responses including “with a little difficulty”, “with some difficulty”, “with much difficulty”, and “unable to do” were recoded to “0”).

PROMIS demographic variable measures. Multiple demographic variables were measured via interview and were included and adjusted in model analyses, such as age, sex, race, education level completed, and other family variables. Participants’ height and weight measurements were taken at mobile examination centers to calculate BMI. The body weight status was defined by four BMI classification groups: underweight ($<18.5 \text{ kg/m}^2$), normal ($18.5 \leq 25 \text{ kg/m}^2$), overweight ($25 \leq 30 \text{ kg/m}^2$), and obese ($\geq 30 \text{ kg/m}^2$).

PROMIS health outcome measures. Healthy and unhealthy subgroups were defined by participants’ responses to questions about chronic conditions. Self-reported chronic diseases were derived from the answers to the clinical questionnaire in PROMIS. In the interviews, chronic disease statuses were determined from the responses to whether ever having been diagnosed by a doctor as having asthma, heart failure, cancer, stroke, arthritis, diabetes, etc. (Table 2).

Table 2

All Health Outcome Items

Health Outcomes	Health Outcomes Items
Hypertension	Have you ever been told by a doctor or a health professional that you have high blood pressure (hypertension)?
Arteries	Have you ever been told by a doctor or a health professional that you have hardening of the arteries (coronary artery disease)?
Heart failure	Have you ever been told by a doctor or a health professional that you have heart failure or congestive heart failure?
Heart attack	Have you ever been told by a doctor or a health professional that you had a heart attack (myocardial infarction)?
Stroke	Have you ever been told by a doctor or a health professional that you had a stroke or transient ischemic attack (TIA)?
Rheumatoid arthritis	Have you ever been told by a doctor or a health professional that you have arthritis or rheumatism?
Osteoarthritis	Have you ever been told by a doctor or a health professional that you have osteoarthritis or degenerative arthritis?
Asthma	Have you ever been told by a doctor or a health professional that you have asthma?
Lung disease	Have you ever been told by a doctor or a health professional that you have chronic lung disease (COPD) or chronic bronchitis or emphysema?
Diabetes	Have you ever been told by a doctor or a health professional that you have diabetes or high blood sugar or sugar in your urine?
Cancer	Have you ever been told by a doctor or a health professional that you have cancer (other than non-melanoma skin cancer)?
Depression	Have you ever been told by a doctor or a health professional that you have depression?
Spinal cord injury	Have you ever been told by a doctor or a health professional that you have a spinal cord injury?
Multiple sclerosis	Have you ever been told by a doctor or a health professional that you have Multiple Sclerosis (MS)?
Parkinson's disease	Have you ever been told by a doctor or a health professional that you had Parkinson's Disease?

Research Procedure

To develop the diagnostic model, the Q-matrix linking physical fitness traits and physical function items should be constructed before modeling. To simplify this procedure, a

thorough literature review was performed to select physical function items initially and gather all potential physical fitness traits used for daily life activities.

Item selection. To make decisions on which items of physical function are effective in the diagnosis model testing, the following two approaches were employed. The first one was based on existing results from IRT modeling on physical function items. Item quality was estimated from traditional IRT models, and several indexes were estimated such as fit statistics and differential item functioning. Regarding problematic items with obvious evidence of misfit, DIF, or similarities with other items, these items were removed from further diagnosis modeling. The second approach was to evaluate the item based on its estimated item parameters in the diagnostic modeling process, which was regarded as a traditional method for item selection in the diagnostic modeling process of education field. Therefore, given the results of estimated item parameters, decisions were made on which items should be included due to their high effectiveness on diagnosis.

Initial physical fitness traits selection. To determine which traits of physical fitness are effective in the diagnosis model testing, a thorough literature review was performed initially: a) searched published articles about physical function questionnaire and fitness components in PubMed and Google Scholar databases; (b) found similar physical function items of this study with physical function items of published articles; and (c) noted the corresponding physical fitness variables of physical function items for further Q-matrix development in this study. Common physical fitness components related with physical function items were recognized through the literature review. For example, according to the hierarchy framework of physical functional status by Reuben (2003), possible underlying physical fitness traits were identified to contain strength, balance, coordination, flexibility, and endurance. Similarly, based on the results

from Suthers and Deeman (2003), indirect performance tests were linked with physical function items from the activities of daily living questionnaire. Those indirect performance tests were designed to measure physical fitness components. Therefore, initial physical fitness traits can be determined.

All determined potential underlying physical fitness traits (Table 3) were provided to the experts as the references.

Table 3

Possible Set of Underlying Physical Fitness Traits Based on Literature Review

Traits	Definition	Example
Muscular Strength	Muscular strength is the strongest force possible that a group of muscles can produce to perform a task.	Push open a heavy door
Flexibility	Flexibility is defined as the range of motion of your joints or the ability of your joints to move freely. It also refers to the mobility of your muscles, which allows for more movement around the joints.	Put on and take off a coat or jacket
Mobility	A person with great mobility is able to perform functional movement patterns with no restrictions in the range of motion of those movements.	Walk a block (100m) on flat ground
Aerobic Endurance	Aerobic endurance, known also as cardiovascular endurance, is a measure of how well a person's lungs and heart can pump oxygen and blood into tissues to facilitate and support moderate exercise.	Run at a fast pace for two miles (3km)
Balance	Balance is the ability to stay upright or stay in control of body movement.	Stand without losing balance for several minutes
Hand-eye Coordination	Hand-eye coordination is the coordinated control of eye movement with hand movement, and the processing of visual input to guide reaching and grasping along with the use of proprioception of the hands to guide the eyes.	Pick up coins from a table top

To explore the underlying physical fitness trait measured by each physical function item, the Q-matrix linking physical fitness traits and physical function items was constructed by the

method of multiple rater inspections. Based on the above potential underlying physical fitness traits, each rater was sent an electronic version of the 112 items from the PROMIS physical function banks.

All raters were asked to provide comments regarding the underlying physical fitness traits appropriateness of the items. A 2-point rating scale (i.e., 0 = “no”, 1 = “yes”) was utilized to determine which underlying physical fitness traits corresponded to an item. For example, the item “Are you able to lift 10 pounds above your shoulder” can be rated as 1 for both muscle strength and flexibility but 0 for other traits such as mobility, aerobic endurance, balance, and hand-eye coordination.

Subsequently, a draft Q-matrix, which is an indication matrix of item characteristics with respect to the attributes (physical fitness traits) involved in each item, was employed for the model development and validation.

Statistical Analysis

Two statistical analyses were conducted in Study I. The first was the Q-matrix development, which addressed specific aim 1 of this study to identify the underlying physical fitness traits from the PROMIS physical function questionnaire, and the second one was a diagnostic model development, which addressed specific aim 2 and 3 of this study.

Q-matrix development. The purpose was to build a reasonable Q-matrix which was used in the later diagnostic model development. Firstly, an exploratory factor analysis was conducted to provide an overview of the numbers of dimensions for the physical function items. Then invited experts rated each item from physical function banks concerning physical fitness

traits. As mentioned Q-matrix was developed by using the multiple-rater inspection method. The statistical analyses involved in the Q-matrix development are described below.

Multiple-rater method. Three experts in the areas of physical function and physical fitness were recruited. Each expert read through all the physical function items and rated items' possible underlying physical fitness traits separately. The following statistical analyses were conducted (Buck et al., 1998; Gierl, Alves, Roberts, & Gotzmann, 2009; Henson & Templin, 2007; Li & Suen, 2013; Sawaki, Kim, & Gentile, 2009):

1. Refined the Q-matrix:
 - a. Checked traits with similar frequencies by calculating the correlation coefficient among all physical fitness traits to estimate their similarities, then determined the necessary to remove or modify any specific trait.
 - b. Checked whether any specific trait was required by many items and consider breaking the trait into two traits or modify the Q-matrix.
 - c. Checked whether too many traits were required by many items and then re-evaluated traits or modify the Q-matrix.
2. Advance refinements were performed based on item parameters (i.e. guessing and slipping) estimated from a preliminary diagnostic model.

Rater agreement. During the Q-matrix construction process, rater agreement was calculated to test the soundness of the Q-matrix. Agreement and multi-raters' Kappa was calculated to determine the inter-rater agreement for each physical fitness trait.

$$kappa = \frac{P_o - P_c}{1 - P_c}, \quad (7)$$

Where P_o is the proportion of agreement and P_c is the proportion of cases in which agreement would have been expected due purely to chance. The final Kappa coefficient can be used to determine the next step of Q-matrix construction. According to Cohen's suggested interpretation, the final Kappa coefficient can be interpreted as: ≤ 0 as indicating no agreement, 0.01–0.20 as none to slight, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as substantial, and 0.81–1.00 as almost perfect agreement (Vrieling et al., 1999). If it is higher than 0.6, which means good agreement, no further refinement of the Q-matrix is needed. Otherwise, low agreement on any physical fitness trait was fixed by assigning most raters' result for the corresponding item in the Q-matrix.

Diagnostic modeling process. Different cognitive diagnostic models, such as DINO model from the compensatory model family, DINA model from the non-compensatory model family, and Generalized DINA (GDINA) model from the general model family, were employed to an existing dataset with the refined Q-matrix. Items' parameters such as guessing, slipping, and discrimination were calculated during the modeling process. According to the definitions of guessing, slipping, and discrimination parameters, in this study, the guessing parameter was identified by the probability that a person responded having difficulties to perform the corresponding activity of the item even though that person was diagnosed to have sufficient physical fitness traits relating to that item. The possible reason could be explained that people who have not performed that activity guessed that their physical function would have limitations on that activity. The slipping parameter was identified by the probability that a person responded having no difficulties to perform the corresponding activity of the item even though that person was diagnosed to have deficient physical fitness traits relating to that item. The discrimination

parameter is used to assess items' capability to discriminate between people with sufficient or deficient fitness traits.

According to formula (3) and (5), the diagnostic modeling process is to estimate the probability that people performed activities relating to items without difficulties. The probability is modeled by only two values that all people who are not expected to perform the activity of one item without difficulties have the chance to perform that activity without difficulties by guessing, and all people who are expected to perform that activity of one item without difficulties have the chance to actually perform that activity of the item without slipping (George, Robitzsch, Kiefer, Groß, & Ünlü, 2016). In the diagnostic modeling process, based on the number of physical fitness traits in the Q-matrix, all participants' possible fitness profiles can be enumerated. Then each possible fitness profile, the Q-matrix, and participants' physical function response data were used to estimate the probability that people performed activities related to items without difficulties. The participant's final fitness profile was determined by the corresponding fitness profile with the highest probability that people performed activities related to items without difficulties.

Model-data fit statistics and item-level misfit statistic were tested among several diagnostic models. Based on log-likelihood statistics, Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), item-level misfit statistic, and model assumptions, the best fit model was selected and its estimated of physical fitness profiles were applied for further analyses.

The diagnostic model was applied to the PROMIS Wave I dataset to explore the underlying physical fitness traits of U.S. adults and to identify the associations between statuses

of physical fitness traits and health outcomes. Several other analyses were conducted as well and are described as follows:

- 1) **Descriptive analysis of each trait:** The prevalence of each physical fitness trait status across demographic characteristics was estimated. The differences of the prevalences of physical fitness trait deficiencies among demographic characteristics were compared in subgroup analyses.
- 2) **Descriptive analysis of profiles:** Descriptive analyses were performed for physical fitness profiles which were fitness patterns composed by all physical fitness traits.
- 3) **Trends with age:** The trends of physical fitness trait deficiencies across age were estimated. Multivariate logistic regression models were applied to test physical fitness traits' trends with continuous age. The differences of trends among each physical fitness trait deficiency were tested. Confounding demographic variables such as sex, race, education level completed, chronic diseases, and self-rated health conditions were included in multiple logistic regression models.
- 4) **Association between physical fitness trait deficiencies and body weight status:** The prevalences of physical fitness trait deficiencies among body weight status were estimated. Multivariate logistic regressions were also conducted to estimate the associations between different body weight status and physical fitness trait deficiencies.
- 5) **Association between physical fitness trait deficiencies and chronic diseases:** The prevalences of physical fitness traits among different chronic diseases, such as diabetes, osteoarthritis, spinal cord injury, stroke, multiple sclerosis, Parkinson's disease, rheumatoid arthritis, asthma, cancer, depression, heart attack, heart failure, hypertension, and lung disease, were estimated. Multivariate logistic regressions were performed to

estimate the associations between physical fitness trait deficiencies and different chronic diseases.

- 6) **Association between cardiometabolic, musculoskeletal, and respiratory diseases and physical fitness trait deficiencies.** The prevalences of physical fitness trait deficiencies among cardiometabolic, musculoskeletal, and respiratory diseases subgroups were calculated. Multivariate logistic regressions were performed to test the associations between disease types and physical fitness trait deficiencies. Confounding variables included all demographic characteristics.
- 7) **Physical fitness trait deficiencies across healthy and unhealthy groups:** Comparison of the prevalences of underlying physical fitness trait deficiencies among healthy and unhealthy subgroups was performed. Multivariate logistic regressions were employed to test the adjusted prevalence of physical fitness trait deficiencies for healthy and unhealthy subgroups. Confounding variables included all demographic characteristics.
- 8) **Physical function score and physical fitness trait statuses.** To validate the diagnostic model, each participant's total score of physical function questionnaire was calculated. To evaluate whether participants with different physical function levels can be segmented by their diagnosed physical fitness trait statuses, t-tests were conducted to find the mean difference of physical function total scores among diagnosed physical fitness trait statuses.

Study II: Cross-Validation of Diagnostic Model

Background

A secondary data source of physical function questionnaires and performance-based fitness levels from a Chinese Parkinson's disease group was used to cross-validate the diagnostic model developed in Study I.

Parkinson's disease, a chronic and invariably progressive neurodegenerative disorder, has many symptoms which disable sufferers and reduce their quality of life (Rahman, Griffin, Quinn, & Jahanshahi, 2008). A study shown that Parkinson's disease could affect approximately 1% of older adults over age 60 and 4% over age 80 (De Lau & Breteler, 2006). People with Parkinson's disease commonly have malfunctions and death of vital nerve cells in the brain. People with Parkinson's disease suffered some movement and coordination issues because their dying neurons in the substantia nigra part of the brain have they have lower ability to produce dopamine which sends messages to control body's movement. Therefore, when the amount of dopamine was reduced, the person will have a lower capacity to intentionally control body movement (Parkinson's Disease Foundation, 2017).

According to a recent study (Prodoehl et al., 2015), the progression of Parkinson's disease leads to impaired balance, decreased walking speed, and reduced muscle strength. This physical function decline trend is a common path for people with Parkinson's disease, that often contributes to falls and other serious health incidents that may result in disability. Since this study concerns physical function, several physical impacts from Parkinson's disease are discussed. According to Poser and Ronthal (1991) patients with Parkinson's disease have higher risks for bradykinesia and rigidity, which often results in issues concerning control and movement of hands, arms, and legs.

Since there are so many physical problems for people with Parkinson's disease, their physical fitness deficiency should be very clear. Because this study focused on physical function decline and physical fitness, a group of individuals with many physical problems was needed so that diagnostic models can be used to obtain and explore their physical problems accurately. Furthermore, using a group who had reduced physical function and physical fitness to validate diagnostic modeling was more meaningful. Additionally, people who would like to understand the possible underlying reasons of physical function decline might have a higher probability to be recruited.

In addition to reasons stated above, the fact that compared with other chronic disease, people with Parkinson's disease having higher likelihood for physical function decline was a consideration. People with Parkinson's disease have a lower level in both physical and mental life quality compared to people with other chronic conditions such as diabetes, stroke, and arthritis (Gage, Hendricks, Zhang, & Kazis, 2003). During the course of disease, a slow loss on both motor function and non-motor function is experienced by people with Parkinson's disease (van der Marck, 2014).

Therefore, considering the above requirements for a group to validate the diagnostic model, the Parkinson's disease group was the most appropriate for this study due to their physical fitness trait status.

Participants and Data Source

A total of 65 participants were recruited and invited by Dr. Zhen Wang's Traditional Chinese Exercise and Health Center at the Shanghai University of Sport, China. Data collection was conducted by Dr. Zhen Wang's lab. Prior to recruitment, invitations, and data collections, this study was approved by the Shanghai University of Sport Research Ethics Review Board and

all inform consent forms were signed by participants. This study used their de-identified data and was approved by the University of Illinois at Urbana-Champaign Institutional Review Board. The inclusion criteria were: (a) 45 yrs. of age or older; (b) diagnosed with Parkinson's disease; and (c) have sufficient vision to read a computer monitor easily. Potential participants were screened for the above inclusion criteria to verify their qualification to take part in the study. All participants who met the inclusion criteria and consented were included. At the end of data collection, 20 participants were removed due to missing responses on physical function questionnaire or values on performance-based physical fitness tests, the remaining 45 participants' data were analyzed in the validation part of the study.

Measures

To cross-validate the diagnostic model developed in Study I, physical function was measured for the Parkinson's disease group using translated into Chinese questionnaires from PROMIS. Physical fitness levels were assessed by performance-based tests to provide a standard criterion for diagnostic model validation. Details about related measures and data collection procedures are described below.

Physical function and characteristics measures. The physical function questionnaire from PROMIS and the characteristic background information questionnaires used in Study I, were translated into Chinese by two separate researchers to assure accuracy and consistency of translated questionnaires which were filled out by the participants.

Performance-based physical fitness measures. To measure the Parkinson's disease group's physical fitness levels, the Fullerton Senior Fitness Test was used since it is proven safe and easy-to-use battery of test items. The Fullerton Senior Fitness Test was developed to assess

the functional fitness of older adults. Its scientific standards for reliability and validity have been tested and confirmed and its performance norms have been developed based on over 7000 participant's tests (Rikli & Jones, 1999). This test can be used to measure aerobic fitness, upper/lower body strength, flexibility, and balance using minimal and inexpensive equipment. The test is composed of 7 functional fitness subtests:

1. 30-second chair stand up

This subtest was to measure the participant's lower body strength, an important ability for daily life activities such as getting out of a chair, onto a bus, or out of a car. The equipment for this test consisted of an armless solid padded chair and a stopwatch. Participants were seated with forearms crossed in front of their chests. Participants stood up and then sat down as often as they were able to do for 30 seconds, the number of complete standing positions in 30 seconds with arms remaining crossed on their chest was recorded as the result (Jones & Rikli, 2002).

2. Arm curl-up

This subtest was to measure the upper body strength required for daily life activities such as carrying laundry and groceries. The equipment consisted of two weights of 5 lbs and 8 lbs, a stopwatch, and an armless straight-back chair. Participants were seated and did curl ups with a weight (woman: 5 lbs; men: 8 lbs) held in their dominate hand. The number of curls completed in 30 seconds was recorded as the score (Jones & Rikli, 2002).

3. 2-min step-up

This subtest was to measure participants' aerobic endurance required for daily life activities such as shopping and walking for a distance. The equipment consisted of a

stopwatch, measuring tape, and visible tape. Participants stood sideways by a wall which had a marked ruler running vertically. Participants then took steps in place. Full steps taken were when the knee came to a point midway between the patella (kneecap) and iliac crest (top hip bone). The final score recorded was the number of times the right knee reached the required height over the 2 minutes (Jones & Rikli, 2002).

4. Chair sit-reach

This subtest was to assess the participant's lower body flexibility, specifically hamstring flexibility needed for keeping balance, helping prevent falls, and walking. The equipment consisted of a chair and a ruler. Participants were seated and extended their legs out with heels on the floor from their sitting position and then reached with their hands with one hand over the other towards their toes. Participants needed to keep the knee straight and hold the reach for 2 seconds. The final score recorded was the number of inches (cm) (+ or -) between extended fingers and tip of toe (Jones & Rikli, 2002).

5. Back-scratch

This subtest was to measure the participant's upper body flexibility needed for daily life activities such as reaching for items on a shelf, changing a lightbulb, or any activity involving shoulder movements. The equipment consisted of a ruler. Participants stood with good posture and reached with one hand over their shoulder and one up the middle of the back, and then the most flexible way was used. The number of inches (cm) between extended middle fingers were recorded as the score in the most flexible way (Jones & Rikli, 2002).

6. 8-foot up and go

This subtest was to measure agility and balance needed for daily life activities such as walking through crowds, moving in unfamiliar environments, and crossing the street before the light changes. The equipment consisted of a chair, a cone or other floor marker, and a stopwatch. Time required to get up from a seated position, walk 8 feet (2.44 m), turn, and return to seated position were recorded as the score (Jones & Rikli, 2002).

7. 6-minute walk

This subtest was to measure aerobic endurance and mobility necessary for daily life activities such as walking distances, climbing stairs, and shopping. The equipment consists of four cones or other floor markers, a measuring wheel, and a stopwatch. Length in yards/meters walked in 6 minutes around a 50-yard course were recorded as the score.

Additionally, two hand-eye coordination assessments were administered. The first was the soda pop test and the second was the cup stacking test. The soda pop test, a well-known documented test of hand-eye coordination (Hoeger & Hoeger, 2015), has participants seated at a table on which 3 cans of soda pop are placed in every other circle on the 6 circles along a straight line. Participants turned the cans upside down in the adjacent circle from right side to left side and then returned all 3 cans to their original position. The time needed to successfully complete this process was recorded (Suomi & Collier, 2003). The cup stacking test (Speed Stacks, Co, 2002), an evidenced effective measure for hand-eye coordination (Fredenburg, Lee, & Solmon, 2001; Udermann, Mayer, Murray, & Sagendorf, 2004), had participants were given basic instructions on the proper mechanics of stacking cups and then they performed a simple cup stacking task using their dominate hand. The time to complete the cup stacking task was recorded as the test result.

Norms for senior fitness test evaluation. The criterion in Table 4 were used to evaluate participants' fitness subtests for men and women. Participants scoring above the normal range were regarded to be above average for their specific age (coded as "1"), whereas those scoring below the normal range were considered as below average (coded as "0").

Table 4

Criterion for Senior Fitness Levels Evaluation (Jones & Rikli, 2002)

	Men						
Age group	60-64	65-69	70-74	75-79	80-84	85-89	90-94
Chair stand up (no. of stands)	14-19	12-18	12-17	11-17	10-15	8-14	7-12
Arm curl-up (no. of reps)	16-22	15-21	14-21	13-19	13-19	11-17	10-14
6-min walk (no. of yds.)	610 - 735	560 - 700	545 - 680	470 - 640	445 - 605	380 - 570	305 - 500
2-min step (no. of steps)	87-115	86-116	80-110	73-109	71-103	59-91	52-86
Chair sit-reach (inches +/-)	-2.5 - +4.0	-3.0 - +3.0	-3.5 - +2.5	-4.0 - +2.0	-5.5 - +1.5	-5.5 - +0.5	-6.5 - -0.5
Back scratch (inches +/-)	-6.5 - 0	-7.5 - -1	-8 - -1	-9 - -2	-9.5 - -2	-10 - -3	-10.5 - -4
8-ft up-&-go (seconds)	5.6-3.8	5.7-4.3	6.0-4.2	7.2-4.6	7.6-5.2	8.9-5.3	10.0-6.2
	Women						
Age group	60-64	65-69	70-74	75-79	80-84	85-89	90-94
Chair stand (no. of stands)	12-17	11-16	10-15	10-15	9-14	8-13	4-11
Arm curl-up (no. of reps)	13-19	12-18	12-17	11-17	10-16	10-15	8-13
6-min walk (no. of yds.)	545 - 660	500 - 635	480 - 615	430 - 585	385 - 540	340 - 510	275 - 440
2-min step (no. of steps)	75-107	73-107	68-101	68-100	60-91	55-85	44-72
Chair sit-reach (inches +/-)	-0.5 - +5.0	-0.5 - +4.5	-1.0 - +4.0	-1.5 - +3.5	-2.0 - +3.0	-2.5 - +2.5	-4.5 - +1.0
Back scratch (inches +/-)	-3.0 - +1.5	-3.5 - +1.5	-4.0 - +1.0	-5.0 - +0.5	-5.5 - +0.0	-7.0 - -1.0	-8.0 - -1.0
8-ft up-&-go (seconds)	6.0-4.4	6.4-4.8	7.1-4.9	7.4-5.2	8.7-5.7	9.6-6.2	11.5-7.3

Statistical Analysis

To address specific aim 4 of this study, diagnose results on underlying physical fitness profiles were compared with performance-based physical fitness levels. Upon the completion of Parkinson's disease group data collection, three ways were used to validate the diagnosed physical fitness traits. Since several estimation methods can be utilized during the diagnostic model development, physical fitness trait statuses were different among these estimation methods, such as Maximum a Posteriori Estimation (MAP), Maximum Likelihood Estimation (MLE), and Expected a Posteriori Estimation (EAP). Thus, the dichotomous results from MAP or MLE and the continuous results from EAP were applied separately during the validation process. To validate the accuracy of estimated physical fitness profiles, several validation analyses were performed and compared.

1. **t-test.** Normality of all performance-based physical fitness test scores was checked. t-tests for performance-based physical fitness test scores across physical fitness trait statuses were conducted. Cohen's *d* effect sizes were calculated as well due to the small sample size.
2. **Correlation test.** The correlation between the estimated continuous probability of physical fitness trait deficiency with the performance-based fitness score was performed. Correlation coefficient Pearson's *r* was computed.
3. **Diagnostic accuracy.** Continuous performance-based physical fitness scores were transformed into binary variables based on the Senior Fitness Criterion. Then, by comparing performance-based physical fitness trait statuses and diagnosed physical fitness trait statuses, several statistics were calculated, including true positives (TP: predicted yes and factual yes), true negatives (TN: predicted no and factual no), false

positives (FP: predicted yes but factual no), and false negatives (FN: predicted no but factual yes). In addition to that, other common statistics for binary classifier were obtained, such as accuracy ($(TP+TN)/(TP+TN+FP+FN)$), sensitivity ($TP/(TP+FN)$), specificity ($TN/(TN+FP)$), and precision ($TP/(TP+FP)$).

Analyses were performed in R 3.3.3 (Team, 2014) using the CDM package (Robitzsch, Kiefer, George, & Uenlue, 2014) for the diagnostic modeling and in SAS 9.3 (SAS Institute, Cary NC) for all other analysis. All statistical tests were 2-tailed and an alpha level of 0.05 was used.

CHAPTER 4: RESULTS

Study I: Development of Diagnostic Model

Q-matrix Development

All 112 items from the PFA and PFB banks of PROMIS were first evaluated based on existing item calibration parameters. Since 15 items were found with misfit statistics, evidence of differential item functioning or similarities with other items, they were removed from further analyses. Based on all three experts' rating results for the remaining 97 physical function items through the Q-matrix development process, the combined Q-matrix used the criterion that for each item and each trait, if there were two or more experts agreed that performing a daily activity in that physical functional item needed a specific physical fitness trait, then the element of Q-matrix linking this item and this trait was recoded as 1; otherwise, it was recoded as 0.

Accordingly, the combined Q-matrix was developed.

Inter-rater agreement: observed proportion of agreement and Kappa coefficient.

Appendix B reports the contingency table of three raters' rating results. Based on this contingency table, multi-raters' observed proportion of agreement and Kappa (Table 5) were calculated to determine the inter-rater agreement for each physical fitness trait. Table 5 reports the observed proportion of agreement and Kappa values for each physical fitness trait among three raters. Regarding the observed proportion of agreement (Po), only mobility (Po = 0.87), and aerobic endurance (Po = 0.89) were detected substantial observed proportion of agreements compared with the other four physical fitness traits. Three raters agreed with each other more on mobility and aerobic endurance than on muscular strength (Po = 0.62) and flexibility (Po = 0.57). Similar results were evidenced by Kappa values. Only mobility (Kappa = 0.70) and aerobic

endurance ($Kappa = 0.65$) found substantial agreements on Kappa values. Hand-eye coordination trait had a moderate agreement on Kappa value ($Kappa = 0.50$). However, lower agreements were found on flexibility ($Kappa = 0.14$), balance ($Kappa = 0.12$), and muscular strength ($Kappa = -0.13$) among the three raters. Because the Kappa coefficient is a chance-corrected measure of agreement, it is possible to be negative, indicating a very poor agreement. In summary, raters' agreements were not good enough on muscular strength, flexibility, and balance, which indicates required further modifications on the combined Q-matrix.

Table 5

Kappa Value for Each Physical Fitness Trait among Three Raters for PROMIS Items

Rater Agreement	Muscular strength	Flexibility	Mobility	Aerobic endurance	Balance	Hand-eye coordination
Po (Proportion of agreement)	0.62	0.57	0.87	0.89	0.70	0.79
Pc (Proportion due to chance)	0.66	0.50	0.56	0.69	0.66	0.57
Kappa	-0.13	0.14	0.70	0.65	0.12	0.50

The soundness of the combined Q-matrix was evaluated according to the following three aspects: (a) checked traits with similar frequencies by conducting correlation analyses among physical fitness traits in the Q-matrix; (b) checked the number of traits required by physical function item banks; and (c) checked the distribution of the number of traits required by items through comparing the three raters' rating with the combined Q-matrix.

Q-matrix soundness. Table 6 reports the similarity of all six physical fitness traits based on their relationship estimation Phi coefficient. Both muscular strength and flexibility had no correlation with other fitness traits. There was a moderately high correlation ($\Phi = 0.615$)

between mobility and aerobic endurance. Furthermore, balance was observed to have a low relationship with mobility ($\Phi = 0.279$) and hand-eye coordination ($\Phi = -0.392$). Since a moderately high correlation between mobility and aerobic endurance was found, modifications on these two fitness traits are needed in the Q-matrix refinement.

Table 6

Phi Coefficient from Correlation Analyses on Q-matrix

Phi	Muscular strength	Flexibility	Mobility	Aerobic endurance	Balance	Hand-eye coordination
Muscular strength	1	-0.173	0.152	0.111	0.029	0.055
Flexibility		1	-0.025	0.011	0.144	0.001
Mobility			1	0.615*	0.279*	-0.193
Aerobic endurance				1	0.131	-0.090
Balance					1	-0.392*
Hand-eye coordination						1

Note: * represents $p < 0.05$.

Table 7 reports percentages of specific physical fitness trait related to items from PROMIS physical function item banks. Regarding all items from PFA and PFB item banks, nearly 95% of items need muscular strength and 84.54% of items require balance. This trend is consistent with percentages of specific physical fitness trait required by items from only PFA item bank or only PFB bank. Flexibility is required by 43.30% items and less than 30% items require mobility, aerobic endurance, or hand-eye coordination. These percentages are likely reasonable except for muscular strength and balance. Since muscular strength and balance are two essential physical fitness components, it is not appropriate to remove these two skills from the Q-matrix purely based on their high percentages. Therefore, given the high percentages of

physical fitness trait requirements by physical function items, the Q-matrix needs to be modified mainly on the muscular strength and balance in the further analyses.

Table 7

Percentage (%) of Physical Fitness Traits Required by Physical Function Item Banks of PROMIS

PROMIS	Muscular Strength	Flexibility	Mobility	Aerobic Endurance	Balance	Hand-eye Coordination
PFA & PFB	94.85	43.30	29.90	18.56	84.54	30.93
PFA- 50 items	92.00	42.00	28.00	20.00	80.00	18.00
PFB- 47 items	97.87	44.68	31.91	17.02	89.36	44.68

Figure 6 shows the distribution of the number of physical fitness traits required by items. According to the results from Rater 1 and Rater 2, few items require one or two physical fitness traits, and most of the items require three or four different physical fitness traits. While according to Rater 3, most of the items require one or two physical fitness traits and only a few items require three or more physical fitness traits. Overall, results from Rater 1 and Rater 2 are very similar on the number of physical fitness traits required by items. Compared to Rater 1 and 2, Rater 3 has a large difference on the rating results. The combined Q-matrix had a similar pattern with the results from Rater 1 and 2. Given when most of the items require 3 or more physical fitness traits, the Q-matrix might cause problems in the diagnostic modeling process (Henson & Templin, 2007), a careful refinement is required to modify the combined Q-matrix to soundly assess the number of traits required by items.

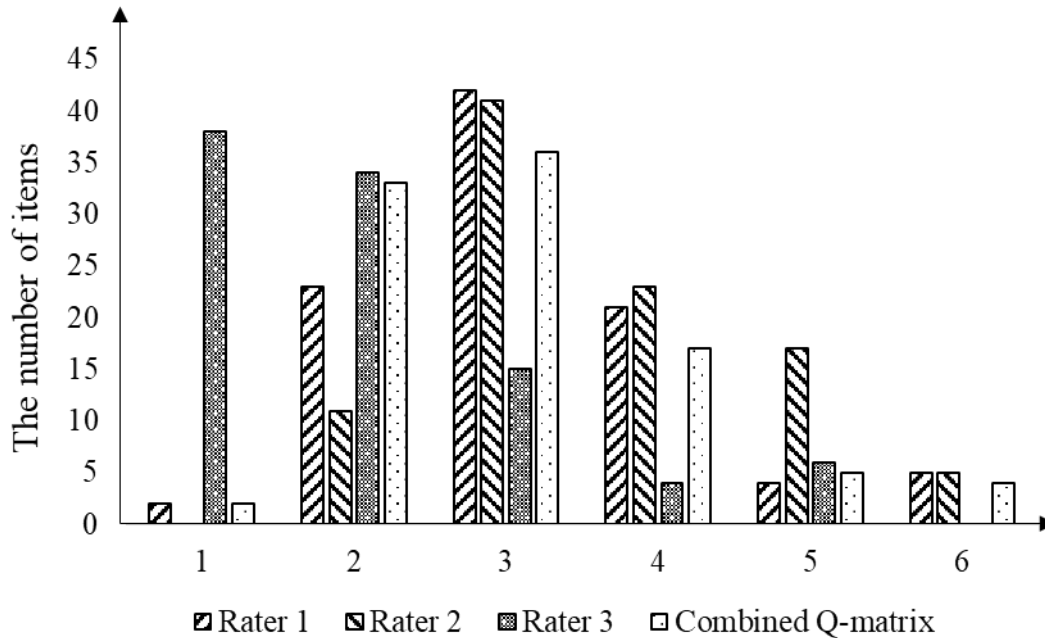


Figure 6. The distribution of the number of physical fitness traits required by items of PROMIS

Q-matrix refinement. According to above analyzed problems of the combined Q-matrix, further refinements are warranted to determine the final Q-matrix for diagnostic analyses. The Q-matrix refinement was conducted as the following steps:

Step 1: The mobility trait was removed due to the following two reasons: One was that the correlation coefficient between mobility and aerobic endurance in the combined Q-matrix was too high; the other reason was that mobility was not a traditional component of physical fitness and mobility has overlap with strength, aerobic endurance, and balance traits;

Step 2: The name of hand-eye coordination was renamed to fine motor skill based on raters' suggestion. Fine motor skill included but was not limited to the hand-eye coordination. Fine motor skill was defined as skills that involve a refined use of the small muscle controlling the hand, fingers, and thumb including reaching, grasping, and manipulating objects (Cuffaro, 2011). Some physical function items such as item PFB37 "Are you able to turn faucets on and

off?” and item PFB41 “Are you able to trim your fingernails?” are a traditional fine motor skill but not only hand-eye coordination;

Step 3: Only major key physical fitness traits were marked down in the modified Q-matrix. According to the combined Q-matrix soundness test results that 94.85% of items required muscular strength and 84.54% of items required balance, physical function items from PROMIS need to be reevaluated to select only major key physical fitness traits which played a significant role to perform that daily activity. For example, the item PFB29 “Are you able to lift a full cup or glass to your mouth?” was rated as requiring muscular strength, flexibility, balance, and hand-eye coordination in the combined Q-matrix. However, compared to other items such as item PFB28 “Are you able to lift 10 pounds above your shoulder” whose major key physical fitness traits are muscular strength and flexibility, the major key physical fitness trait required by the item PFB29 should be fine motor skill. Therefore, all physical function items from PFA and PFB were re-evaluated to only retain major key physical fitness traits for each item;

Step 4: Further refinements were conducted based on item parameters, such as guessing, slipping, and discrimination parameters, which were estimated from a preliminary diagnostic modeling. Since the diagnostic modeling process required the summation of guessing and slipping parameters not exceeding 1, items that disobeyed this rule were removed. Furthermore, to make sure all items had high discrimination, only items close to or larger than 0.2 were retained. Since DINA model is the most common conjunctive model belonging to the non-compensatory model family, it was employed as the preliminary diagnostic model that estimated guessing, slipping parameters, and discrimination values. All participants (n = 942) involved in the PROMIS Wave I study that responded to physical function items of PFA and PFB banks were included. Participants who failed to respond to all physical function items were removed and 722

participants were retained for further multiple logistic regressions. Table 8 reports all guessing, slipping, and discrimination parameters of each physical function item.

According to above parameters' criteria, no item was removed due to high values on the summation of guessing and slipping parameters. Items PFA13, PFA29, PFA35, PFA40, PFA47, PFA50, PFB07, PFB08, PFB10, PFB11, PFB13, PFB16, PFB19, PFB20, PFB22, PFB25, PFB27, PFB29, PFB31, PFB32, PFB36, and PFB49 were removed from the Q-matrix and further diagnostic modeling process due to low values on discrimination (less than 0.2).

Table 8

Guessing, Slipping, and Discrimination Parameters for Each Item from PROMIS

Item	Guessing	Slipping	IDI	Item	Guessing	Slipping	IDI	Item	Guessing	Slipping	IDI
PFA01	0.000	0.435	0.565	PFA39	0.759	0.018	0.223	PFB19	0.834	0.000	0.166
PFA02	0.235	0.124	0.642	PFA40	0.815	0.002	0.183	PFB20	0.839	0.010	0.151
PFA03	0.243	0.044	0.712	PFA41	0.334	0.081	0.585	PFB21	0.347	0.076	0.577
PFA04	0.432	0.030	0.538	PFA42	0.712	0.004	0.284	PFB22	0.881	0.002	0.117
PFA05	0.04	0.432	0.528	PFA43	0.772	0.010	0.218	PFB23	0.580	0.002	0.418
PFA06	0.371	0.05	0.579	PFA44	0.382	0.080	0.538	PFB24	0.764	0.024	0.212
PFA08	0.708	0.002	0.290	PFA45	0.320	0.017	0.664	PFB25	0.859	0.000	0.141
PFA09	0.489	0.057	0.454	PFA47	0.880	0.002	0.118	PFB26	0.655	0.005	0.339
PFA10	0.688	0.008	0.304	PFA48	0.658	0.025	0.316	PFB27	0.809	0.004	0.187
PFA11	0.013	0.66	0.327	PFA49	0.530	0.024	0.447	PFB28	0.497	0.021	0.482
PFA12	0.041	0.191	0.768	PFA50	0.824	0.002	0.174	PFB29	0.941	0.002	0.057
PFA13	0.828	0.006	0.166	PFA51	0.722	0.000	0.278	PFB30	0.768	0.005	0.226
PFA14	0.196	0.05	0.755	PFA52	0.565	0.016	0.419	PFB31	0.870	0.000	0.130
PFA15	0.709	0.018	0.273	PFA53	0.742	0.002	0.256	PFB32	0.891	0.004	0.105
PFA16	0.389	0.010	0.600	PFA54	0.085	0.125	0.789	PFB33	0.507	0.014	0.479
PFA17	0.088	0.232	0.68	PFA55	0.509	0.014	0.476	PFB34	0.074	0.198	0.728
PFA18	0.118	0.111	0.771	PFA56	0.479	0.032	0.489	PFB36	0.882	0.004	0.114
PFA19	0.018	0.363	0.619	PFB01	0.359	0.022	0.619	PFB37	0.348	0.040	0.612
PFA20	0.081	0.261	0.659	PFB03	0.617	0.006	0.376	PFB39	0.201	0.045	0.754
PFA21	0.66	0.030	0.310	PFB04	0.564	0.004	0.432	PFB40	0.066	0.213	0.721

Table 8 (cont.)

Item	Guessing	Slipping	IDI	Item	Guessing	Slipping	IDI	Item	Guessing	Slipping	IDI
PFA23	0.111	0.149	0.740	PFB05	0.681	0.004	0.315	PFB41	0.145	0.064	0.791
PFA27	0.076	0.379	0.545	PFB07	0.804	0.006	0.190	PFB42	0.642	0.008	0.350
PFA28	0.435	0.078	0.487	PFB08	0.856	0.004	0.140	PFB43	0.776	0.004	0.220
PFA29	0.811	0.008	0.181	PFB09	0.538	0.023	0.439	PFB44	0.423	0.008	0.569
PFA30	0.734	0.000	0.266	PFB10	0.856	0.002	0.142	PFB45	0.055	0.293	0.652
PFA31	0.636	0.013	0.351	PFB11	0.865	0.000	0.135	PFB48	0.221	0.097	0.682
PFA32	0.629	0.012	0.359	PFB12	0.650	0.010	0.340	PFB49	0.818	0.008	0.174
PFA33	0.031	0.736	0.234	PFB13	0.851	0.004	0.145	PFB50	0.621	0.012	0.366
PFA34	0.03	0.184	0.786	PFB14	0.778	0.008	0.214	PFB51	0.525	0.019	0.456
PFA35	0.863	0.000	0.137	PFB15	0.790	0.000	0.210	PFB54	0.054	0.387	0.560
PFA36	0.111	0.18	0.709	PFB16	0.868	0.002	0.130	PFB56	0.297	0.057	0.646
PFA37	0.047	0.062	0.892	PFB17	0.104	0.162	0.734				
PFA38	0.774	0.006	0.220	PFB18	0.790	0.002	0.208				

Note: IDI is the item discrimination index

After the four refinements steps on the combined Q-matrix, the final refined Q-matrix is presented in Table 9. To further check the soundness of the final refined Q-matrix, the Phi coefficients among physical fitness traits were estimated (Table 10). Muscular strength was found to have moderate correlations with aerobic endurance, balance, and low correlation with fine motor skill. Flexibility was observed a low correlation with fine motor skill. Aerobic endurance was found to have a moderate relationship with balance. Since the above moderate relationships were acceptable, no further modification of physical fitness traits was needed.

Table 9

The Refined Q-matrix Used in the Further Analysis

Item	Muscular strength	Flexibility	Aerobic endurance	Balance	Fine Motor skill	Item	Muscular strength	Flexibility	Aerobic endurance	Balance	Fine Motor skill
PFA01	1	1	1	1	0	PFA51	0	0	0	1	0
PFA02	1	1	1	1	0	PFA52	0	0	0	0	1
PFA03	1	1	0	1	0	PFA53	1	1	1	1	0
PFA04	1	1	1	1	0	PFA54	0	0	0	0	1
PFA05	1	0	0	1	0	PFA55	0	1	0	1	0
PFA06	0	1	0	1	0	PFA56	0	1	0	0	0
PFA08	1	0	0	1	0	PFB01	1	1	1	1	0
PFA09	0	1	0	0	0	PFB03	1	0	0	1	0
PFA10	1	0	1	1	0	PFB04	1	1	1	1	0
PFA11	1	1	0	1	0	PFB05	1	1	1	1	0
PFA12	1	0	0	0	0	PFB09	1	0	0	0	0
PFA14	1	0	0	1	0	PFB12	0	1	0	1	1
PFA15	1	0	0	1	0	PFB14	0	1	0	0	0
PFA16	0	1	0	1	1	PFB15	0	0	0	0	1
PFA17	0	1	0	0	0	PFB17	0	1	0	0	1
PFA18	0	0	0	0	1	PFB18	0	0	0	0	1
PFA19	1	0	1	1	0	PFB21	0	0	0	0	1
PFA20	0	0	0	0	1	PFB23	0	0	0	0	1
PFA21	1	1	0	1	0	PFB24	1	1	0	1	0
PFA23	1	0	1	1	0	PFB26	0	1	0	0	0
PFA27	1	0	1	1	0	PFB28	1	1	0	0	0
PFA28	1	0	0	0	1	PFB30	1	0	0	0	1
PFA30	0	0	0	1	0	PFB33	0	1	0	0	0
PFA31	1	1	0	1	0	PFB34	0	1	0	0	1
PFA32	0	0	0	1	0	PFB37	0	0	0	0	1
PFA33	0	0	1	0	0	PFB39	1	1	0	0	1
PFA34	0	1	0	0	0	PFB40	1	0	0	1	0
PFA36	0	1	0	0	0	PFB41	0	0	0	0	1
PFA37	0	0	0	1	0	PFB42	0	0	1	1	0
PFA38	0	1	0	0	0	PFB43	1	1	0	1	1
PFA39	1	0	1	1	0	PFB44	1	1	1	1	0
PFA41	1	0	0	1	0	PFB45	1	1	1	1	0
PFA42	1	1	0	1	0	PFB48	0	1	0	1	0
PFA43	0	0	0	0	1	PFB50	1	1	1	1	1

Table 9 (cont.)

Item	Muscular strength	Flexibility	Aerobic endurance	Balance	Fine Motor skill	Item	Muscular strength	Flexibility	Aerobic endurance	Balance	Fine Motor skill
PFA44	0	1	0	0	0	PFB51	1	1	1	1	1
PFA45	1	1	0	1	0	PFB54	1	1	0	1	0
PFA48	0	0	0	0	1	PFB56	1	1	0	0	0
PFA49	0	1	0	0	0						

Table 10

Phi Coefficient from Correlation Analyses of the Final Refined Q-matrix

Phi	Muscular strength	Flexibility	Aerobic endurance	Balance	Fine motor skill
Muscular strength	1	0.090	0.415*	0.546*	-0.319*
Flexibility		1	0.073	0.110	-0.237*
Aerobic endurance			1	0.435*	-0.225
Balance				1	-0.432*
Fine motor skill					1

Note: * represents $p < 0.05$.

Table 11 reports the percentage of physical fitness traits in the final refined Q-matrix required by the PROMIS item banks. Muscular strength, flexibility, and balance were related to slightly over 50% of the items and less than 30% of items required aerobic endurance and fine motor skill. Thus, these percentages are balanced by fitness traits and are reasonable.

Table 11

Percentage (%) of Physical Fitness Traits Required by Item Banks in the Final Refined Q-matrix

PROMIS	Muscular Strength	Flexibility	Aerobic Endurance	Balance	Fine Motor skill
PFA & PFB	52.00	54.67	24.00	56.00	29.33
PFA (44 items)	50.00	47.73	22.73	61.36	18.18
PFB (31 items)	54.84	64.52	25.81	48.39	45.16

Table 12 reports the number and percentage of physical fitness traits related to items in the combined Q-matrix and final refined Q-matrix. Compared to the combined Q-matrix with over 60% of items requiring 3 or more physical fitness traits, after the Q-matrix refinements, 40% of items required a single physical fitness trait and nearly 23% of items required two physical fitness traits in the refined Q-matrix. Very few items (less than 3%) needed 5 or more physical fitness traits. These results show the soundness of the final refined Q-matrix.

Table 12

Number and Percentage of Physical Function Items Across the Number of Physical Fitness Traits Required in the Combined Q-matrix and the Final Refined Q-matrix

# of physical fitness trait related to items	N (%) of item in Q-matrix	
	Combined Q-matrix	Refined Q-matrix
1	2 (2.06)	30 (40.00)
2	33 (34.02)	17 (22.67)
3	36 (37.11)	16 (21.33)
4	17 (17.53)	10 (13.33)
5	5 (5.15)	2 (2.67)
6	4 (4.12)	0 (0.00)

The final refined Q-matrix was identified after the above further refinements. Table 13 reports each item's guessing, slipping, and discrimination parameters in the final refined Q-matrix. No problematic item was found on their high values of the summation of guessing and slipping parameters. Except for item PFB15 and PFB18, all other items have discrimination values larger than 0.2. Since discrimination values of PFB15 and PFB18 were very close to 0.2 and only slightly decreased by 0.014 and 0.024 in the final refined Q-matrix, it was decided to keep these two items in the final refined Q-matrix for further analyses.

Table 13

Guessing, Slipping, and Discrimination Parameters of Items in the Final Refined Q-matrix

Item	Guessing	Slipping	IDI	Item	Guessing	Slipping	IDI	Item	Guessing	Slipping	IDI
PFA01	0.000	0.434	0.566	PFA33	0.024	0.738	0.238	PFB14	0.784	0.012	0.204
PFA02	0.242	0.129	0.629	PFA34	0.019	0.195	0.786	PFB15	0.804	0.000	0.196
PFA03	0.278	0.038	0.684	PFA36	0.107	0.191	0.703	PFB17	0.090	0.160	0.750
PFA04	0.430	0.030	0.540	PFA37	0.064	0.052	0.884	PFB18	0.812	0.004	0.184
PFA05	0.034	0.411	0.555	PFA38	0.789	0.008	0.204	PFB21	0.359	0.072	0.569
PFA06	0.350	0.058	0.592	PFA39	0.772	0.020	0.208	PFB23	0.612	0.002	0.386
PFA08	0.712	0.002	0.286	PFA41	0.364	0.071	0.565	PFB24	0.768	0.024	0.208
PFA09	0.454	0.064	0.482	PFA42	0.721	0.003	0.276	PFB26	0.656	0.007	0.337
PFA10	0.688	0.009	0.303	PFA43	0.785	0.011	0.204	PFB28	0.501	0.021	0.477
PFA11	0.011	0.659	0.330	PFA44	0.396	0.079	0.526	PFB30	0.760	0.004	0.236
PFA12	0.075	0.159	0.766	PFA45	0.326	0.018	0.656	PFB33	0.489	0.022	0.489
PFA14	0.240	0.047	0.712	PFA48	0.679	0.023	0.298	PFB34	0.067	0.179	0.754
PFA15	0.728	0.015	0.256	PFA49	0.526	0.023	0.452	PFB37	0.376	0.047	0.576
PFA16	0.429	0.011	0.561	PFA51	0.738	0.000	0.262	PFB39	0.203	0.040	0.757
PFA17	0.076	0.231	0.693	PFA52	0.587	0.013	0.400	PFB40	0.076	0.187	0.737
PFA18	0.142	0.096	0.762	PFA53	0.753	0.001	0.245	PFB41	0.180	0.046	0.775
PFA19	0.017	0.347	0.636	PFA54	0.105	0.105	0.790	PFB42	0.651	0.009	0.340
PFA20	0.081	0.244	0.675	PFA55	0.493	0.013	0.495	PFB43	0.784	0.005	0.211
PFA21	0.658	0.027	0.314	PFA56	0.485	0.033	0.483	PFB44	0.444	0.008	0.547
PFA23	0.110	0.151	0.739	PFB01	0.372	0.015	0.613	PFB45	0.052	0.284	0.664
PFA27	0.080	0.375	0.545	PFB03	0.671	0.009	0.320	PFB48	0.229	0.097	0.674
PFA28	0.456	0.072	0.472	PFB04	0.571	0.004	0.425	PFB50	0.626	0.013	0.361
PFA30	0.730	0.001	0.269	PFB05	0.677	0.004	0.319	PFB51	0.537	0.022	0.440
PFA31	0.652	0.014	0.334	PFB09	0.585	0.022	0.393	PFB54	0.048	0.377	0.574
PFA32	0.617	0.013	0.370	PFB12	0.651	0.012	0.336	PFB56	0.294	0.055	0.651

Diagnostic Modeling Process

To find the best model for diagnostic analysis of physical function items, this study primarily selected three typical models from three different model families: the DINO model from the compensatory model family, the DINA model from the non-compensatory model

family, and the GDINA model from the general model family. These three diagnostic models and the final refined Q-matrix were applied to the PROMIS Wave I dataset.

Table 14 reports the three models' model-data fit statistics and item-level misfit statistics. According to the results of the diagnostic modeling process, GDINA model was not appropriate to be used in this case because too many parameters from the GDINA model needed to be estimated. The DINO and DINA models were compared and the DINA model had relatively low values on log-likelihood, AIC, and BIC, even though the item-level misfit index was slightly higher than in DINO. Considering another perspective, DINA model was the most appropriate model due to the following reason: As a non-compensatory model, DINA model assumes that one attribute cannot be compensated by other skills, which is consistent with the definition of physical fitness components. Each physical fitness component should be independently essential for people's physical function, and none of them can be replaced by other components. Therefore, DINA model was selected for further analyses.

Table 14

Model Fit Indexes and Item-level Misfit Index Among Three Models

Models	Relative model fit indexes among three models				Item-level misfit index
	Log-Likelihood	Deviance	AIC	BIC	Root Mean Squared Error
DINO	-20198.90	40397.74	40759.74	41637.23	0.09
DINA	-20038.40	40076.71	40438.71	41316.20	0.11
GDINA	-18058.80	36117.56	37109.56	39514.17	0.18

There are three estimation methods among the DINA model that can be used to estimate the final profile of physical fitness including MAP, MLE, and EAP (with 0.5 as a default cutoff score). All these three methods were tested to check their similarities and differences. According

to the comparison results of these three estimation methods (Table 15), significant similarities were found because of their high values on the proportion of agreement and Kappa. Since results from these three estimation methods were highly consistent, the MAP method which is much complicated and has a reasonable assumption (i.e., assume number of people with different physical fitness trait profiles are not roughly equal) was selected for further analyses instead of the MLE method. At the same time, the EAP method which could provide a continuous probability was also applied for further analyses when there is a need for continuous estimation results for each physical fitness trait.

Table 15

Proportion of Agreement and Kappa Value for Each Physical Fitness Trait Among Three Estimation Methods

Index	Muscular strength	Flexibility	Aerobic endurance	Balance	Hand-eye coordination
P	0.99	0.99	0.95	1.00	0.98
Pc	0.63	0.59	0.60	0.68	0.60
Kappa	0.96	0.98	0.88	1.00	0.95

To reveal associations between statuses of physical fitness traits and health outcomes, the DINA diagnostic model estimation results were linked with participants' demographic characteristics and health outcomes in the following association analyses.

Descriptive Analysis of Each Trait

Table 16 reports individual characteristics of the 942 participants aged 18 years and older in the PROMIS Wave I study. Among them, 51.17% were women and over 77% were White.

The majority (77.07%) had completed higher education than high school. Nearly 62% of participants were married at the time of the study. The percentage of underweight, normal weight, overweight, and obese groups were 1.50%, 32.51%, 35.41%, and 30.58%, respectively.

Table 17 shows descriptive statistics for all participants in the PROMIS Wave I study across each physical fitness trait status. After the diagnostic modeling on participants' physical function responses data, each participant was diagnosed on his/her status of muscular strength, flexibility, aerobic endurance, balance, and fine motor skill. The diagnostic results were dichotomous (0 means deficiency in this specific physical fitness trait; 1 means sufficiency in this particular physical fitness trait). According to the diagnosed fitness results, 29.40% of participants were found deficient in muscular strength. Among them, 54.67% were women and almost half (47.66%) were aged 60 and older. 70.56% of participants with muscular strength deficiency were married, and only 8.25% of participants with deficiency in muscular strength were having a family income equal or more than \$100,000. Almost half of participants (45.75%) with muscular strength deficiency were obese.

Similar patterns were identified on flexibility deficiency. There were 29.81% of participants found with flexibility deficiency. Among them, 55.76% were women and 50% were 60 years and older. 82.49% of participants with flexibility deficiency were White and 70.97% of them were married. Most of the participants having a deficiency in flexibility were overweight (31.63%) or obese (44.65%).

There were 35.16% of participants identified to be deficient in aerobic endurance. Among those with aerobic endurance deficiency, 54.69% were women and 50% were 60 years and older. Most of the participants with deficiency in aerobic endurance were White (81.25%)

and married (68.75%). Meanwhile, 32.68% and 42.52% of participants with aerobic endurance deficiency were overweight or obese, respectively.

Based on the diagnostic results, 24.04% of participants were identified balance deficiency. Among those adults, 59.43% were women and over half (52.57%) were 60 years and older. 71.43% participants with balance deficiency had completed higher education than high school and 68% of those with balance deficiency were married. Most of the participants with balance deficiency were overweight (31.21%) or obese (43.35%).

30.91% of participants were recognized to be deficient in fine motor skill. Among those with fine motor skill deficiency, 55.56% were women and 51.56% were 60 years and older. Most of the participants with deficiency in fine motor skill were White (83.11%) and married (69.33%). As with the other fitness trait deficiencies, 34.08% and 41.70% of participants with fine motor skill deficiency were overweight or obese, respectively.

Table 16

Descriptive Statistics for All Participants in the PROMIS Dataset

Individual characteristics		N (%) or Mean (SD)
Sex	Men	460 (48.83)
	Women	482 (51.17)
Age		49.97(19.45)
Education	Less than high school	17 (1.81)
	High school grad	198 (21.09)
	More than high school	724 (77.10)
Race	White	726 (77.07)
	Black	93 (9.87)
	Asian	6 (0.64)
	American Indian/Alaska Native	5 (0.53)
	Other	112 (11.89)

Table 16 (*cont.*)

Individual characteristics		N (%) or Mean (SD)
BMI		27.92 (6.01)
Marital status		
	Never married	204 (21.68)
	Married	578 (61.42)
	Others	159 (16.90)
Family income		
	Less than \$20,000	109 (11.87)
	\$20,000 - \$49,999	333 (36.27)
	\$50,000 - \$99,999	324 (35.29)
	100,000 or more	152 (16.56)
Body weight status		
	Underweight	14 (1.50)
	Normal weight	303 (32.51)
	Overweight	330 (35.41)
	Obese	285 (30.58)

Table 17

Descriptive Statistics (N, %) for all Participants Across Each Physical Fitness Trait Status in PROMIS Dataset

Individual characteristics	Muscular strength		Flexibility		Aerobic endurance		Balance		Fine motor skill	
	Deficiency	Sufficiency	Deficiency	Sufficiency	Deficiency	Sufficiency	Deficiency	Sufficiency	Deficiency	Sufficiency
Total	214 (29.40)	514 (70.60)	217 (29.81)	511 (70.19)	256 (35.16)	472 (64.84)	175 (24.04)	553 (75.96)	225 (30.91)	503 (69.09)
Sex										
Men	97 (45.33)	262 (50.97)	96 (44.24)	263 (51.47)	116 (45.31)	243 (51.48)	71 (40.57)	288 (52.08)	100 (44.44)	259 (51.49)
Women	117 (54.67)	252 (49.03)	121 (55.76)	248 (48.53)	140 (54.69)	229 (48.52)	104 (59.43)	265 (47.92)*	125 (55.56)	244 (48.51)
Age										
18-39	27 (12.62)	233 (45.51)	28 (12.96)	232 (45.49)	39 (15.23)	221 (47.02)	19 (10.86)	241 (43.74)	28 (12.44)	232 (46.31)
40-59	85 (39.72)	165 (32.23)	80 (37.04)	170 (33.33)	89 (34.77)	161 (34.26)	64 (36.57)	186 (33.76)	81 (36.00)	169 (33.73)
Above 60	102 (47.66)	114 (22.27)*	108 (50.00)	108 (21.18)*	128 (50.00)	88 (18.72)*	92 (52.57)	124 (22.50)*	116 (51.56)	100 (19.96)*
Education										
Less than high school	6 (2.80)	6 (1.17)	8 (3.70)	4 (0.78)	8 (3.13)	4 (0.85)	4 (2.29)	8 (1.45)	7 (3.11)	5 (1.00)
High school grad	50 (23.36)	99 (19.34)	50 (23.15)	99 (19.41)	62 (24.22)	87 (18.51)	46 (26.29)	103 (18.69)	55 (24.44)	94 (18.76)
More than high school	158 (73.83)	407 (79.49)	158 (73.15)	407 (79.80)*	186 (72.66)	379 (80.64)*	125 (71.43)	440 (79.85)	163 (72.44)	402 (80.24)*
Race										
White	175 (81.78)	388 (75.49)	179 (82.49)	384 (75.15)	208 (81.25)	355 (75.21)	142 (81.14)	421 (76.13)	187 (83.11)	376 (74.75)
Black	17 (7.94)	61 (11.87)	16 (7.37)	62 (12.13)	22 (8.59)	56 (11.86)	14 (8.00)	64 (11.57)	16 (7.11)	62 (12.33)
Asian	0 (0.00)	4 (0.78)	0 (0.00)	4 (0.78)	0 (0.00)	4 (0.85)	0 (0.00)	4 (0.72)	0 (0.00)	4 (0.80)
American Indian /Alaska Native	1 (0.47)	2 (0.39)	1 (0.46)	2 (0.39)	1 (0.39)	2 (0.42)	1 (0.57)	2 (0.36)	1 (0.44)	2 (0.40)
Other	21 (9.81)	59 (11.48)	21 (9.68)	59 (11.55)	25 (9.77)	55 (11.65)	18 (10.29)	62 (11.21)	21 (9.33)	59 (11.73)

Table 17 (cont.)

Individual characteristics	Muscular strength		Flexibility		Aerobic endurance		Balance		Fine motor skill	
	Deficiency	Sufficiency	Deficiency	Sufficiency	Deficiency	Sufficiency	Deficiency	Sufficiency	Deficiency	Sufficiency
Marital status										
Never Married	18 (8.41)	144 (28.02)	17 (7.83)	145 (28.38)	27 (10.55)	135 (28.60)	15 (8.57)	147 (26.58)	19 (8.44)	143 (28.43)
Married	151 (70.56)	303 (58.95)	154 (70.97)	300 (58.71)	176 (68.75)	278 (58.90)	119 (68.00)	335 (60.58)	156 (69.33)	298 (59.24)
Others	45 (21.03)	67 (13.04)*	46 (21.20)	66 (12.92)*	53 (20.70)	59 (12.50)*	41 (23.43)	71 (12.84)*	50 (22.22)	62 (12.33)*
Family income										
Less than \$20,000	31 (15.05)	49 (9.65)	28 (13.59)	52 (10.24)	37 (15.04)	43 (9.19)	23 (13.86)	57 (10.40)	30 (13.89)	50 (10.04)
\$20,000 - \$49,999	90 (43.69)	157 (30.91)	98 (47.57)	149 (29.33)	111 (45.12)	136 (29.06)	82 (49.40)	165 (30.11)	101 (46.76)	146 (29.32)
\$50,000 - \$99,999	68 (33.01)	202 (39.76)	60 (29.13)	210 (41.34)	75 (30.49)	195 (41.67)	47 (28.31)	223 (40.69)	63 (29.17)	207 (41.57)
100,000 or more	17 (8.25)	100 (19.69)*	20 (9.71)	97 (19.09)*	23 (9.35)	94 (20.09)*	14 (8.43)	103 (18.80)*	22 (10.19)	95 (19.08)*
Body weight status										
Underweight	3 (1.42)	6 (1.17)	3 (1.40)	6 (1.18)	3 (1.18)	6 (1.28)	3 (1.73)	6 (1.09)	3 (1.35)	6 (1.20)
Normal weight	43 (20.28)	180 (35.16)	48 (22.33)	175 (34.38)	60 (23.62)	163 (34.68)	41 (23.70)	182 (33.03)	51 (22.87)	172 (34.33)
Overweight	69 (32.55)	191 (37.30)	68 (31.63)	192 (37.72)	83 (32.68)	177 (37.66)	54 (31.21)	206 (37.39)	76 (34.08)	184 (36.73)
Obese	97 (45.75)	135 (26.37)*	96 (44.65)	136 (26.72)*	108 (42.52)	124 (26.38)*	75 (43.35)	157 (28.49)*	93 (41.70)	139 (27.74)*

Note: * represents significant chi-square test results.

Chi-square tests among individual characteristics and physical fitness trait deficiencies were conducted primarily to evaluate their possible relationships. Age groups, marital status, family income, and body weight status showed obvious relationships with all five physical fitness trait deficiencies. Sex was only found to be correlated with balance deficiency. To more deeply analyze these relationships, multiple logistic regressions were conducted to consider possible confounding variables.

Descriptive Analysis of Profiles and the Number of Physical Fitness Trait Deficiencies

Physical fitness profiles were composed of all physical fitness trait statuses. It was found that two physical fitness profiles had higher prevalences than other patterns: 00000 and 11111. The “00000” profile refers people deficient in muscular strength, flexibility, aerobic endurance, balance, and fine motor skill and the “11111” profile refers people had no deficiency in those five physical fitness traits. According to Table 18, there was 4.95% of people having 00010 physical fitness profile which indicates only having sufficient balance among all five fitness traits. 3.02% of people were identified having profile of 11011 which meant only deficient in aerobic endurance but sufficient in other traits. 34.72% of participants 60 years and older were diagnosed to be deficient in all five fitness traits. 7.76% of obese people were 00010, thus only have a sufficiency skill in balance and deficient in the other four fitness traits. For chronic disease, 62.5% and 71.43% of people with osteoarthritis and spinal cord injury have profile 00000, respectively. 11.11% and 10.95% of people with stroke and rheumatoid arthritis were diagnosed to have fitness profile of 00010.

Table 19 reports the participants’ demographic statistics across the number of physical fitness trait deficiencies. Similarly, 62.91% of people were found to have no deficiency in any physical fitness trait (11111) and 21.15% of people were diagnosed to be deficient in all physical

fitness traits (00000). 12.96% and 34.71% of people 60 years and older have deficiencies in four fitness traits and five fitness traits, respectively. Compared to people classified as overweight, obese people have higher prevalences of four physical fitness traits' deficiency (9.91% vs. 7.69%) and five physical fitness traits' deficiency (29.31% vs. 17.31%). Regarding chronic diseases, the relatively higher percentages of people with some chronic diseases were found to be deficient in 4 or more physical fitness traits when compared to people without a chronic disease. For example, above 60% of diabetics have 4 or 5 physical fitness traits deficiencies. More than 75% of people with rheumatoid arthritis were diagnosed to be deficient in two or more fitness traits.

Table 18

Descriptive Statistics (N, %) for all Participants of PROMIS Across Physical Fitness Profiles

Individual characteristics	Physical fitness profiles						
	11111	00000	00010	11011	10000	01011	Others
Total	458 (62.91)	154 (21.15)	36 (4.95)	22 (3.02)	15 (2.06)	14 (1.92)	29 (3.99)
Sex							
Men	236 (65.74)	62 (17.27)	22 (6.13)	11 (3.06)	6 (1.67)	8 (2.23)	14 (3.9)
Women	222 (60.16)	92 (24.93)	14 (3.79)	11 (2.98)	9 (2.44)	6 (1.63)	15 (4.07)
Age							
18-39	219 (84.23)	17 (6.54)	7 (2.69)	9 (3.46)	0 (0.00)	2 (0.77)	6 (2.31)
40-59	158 (63.2)	62 (24.80)	14 (5.60)	4 (1.60)	2 (0.80)	5 (2.00)	5 (2.00)
Above 60	80 (37.04)	75 (34.72)	15 (6.94)	9 (4.17)	13 (6.02)	7 (3.24)	17 (7.87)
Education							
Less than high school	4 (33.33)	2 (16.67)	4 (33.33)	0 (0.00)	1 (8.33)	0 (0.00)	1 (8.33)
High school grad	85 (57.05)	40 (26.85)	6 (4.03)	5 (3.36)	4 (2.68)	4 (2.68)	5 (3.36)
More than high school	368 (65.13)	112 (19.82)	26 (4.60)	17 (3.01)	10 (1.77)	10 (1.77)	22 (3.89)
Race							
White	343 (60.92)	124 (22.02)	32 (5.68)	15 (2.66)	13 (2.31)	10 (1.78)	26 (4.62)
Black	56 (71.79)	13 (16.67)	2 (2.56)	4 (5.13)	1 (1.28)	2 (2.56)	0 (0.00)
Asian	4 (100.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
American Indian/Alaska Native	2 (66.67)	1 (33.33)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Other	53 (66.25)	16 (20.00)	2 (2.50)	3 (3.75)	1 (1.25)	2 (2.50)	3 (3.75)
Marital status							
Never Married	133 (82.10)	12 (7.41)	3 (1.85)	7 (4.32)	0 (0.00)	2 (1.23)	5 (3.09)
Married	269 (59.25)	108 (23.79)	28 (6.17)	12 (2.64)	8 (1.76)	9 (1.98)	20 (4.41)
Others	56 (50.00)	34 (30.36)	5 (4.46)	3 (2.68)	7 (6.25)	3 (2.68)	4 (3.57)
Family income							
Less than \$20,000	41 (51.25)	21 (26.25)	5 (6.25)	6 (7.50)	1 (1.25)	3 (3.75)	3 (3.75)
\$20,000 - \$49,999	132 (53.44)	70 (28.34)	14 (5.67)	6 (2.43)	10 (4.05)	4 (1.62)	11 (4.45)
\$50,000 - \$99,999	189 (70.00)	43 (15.93)	12 (4.44)	8 (2.96)	2 (0.74)	7 (2.59)	9 (3.33)

Table 18 (cont.)

Individual characteristics	Physical fitness profiles						
	11111	00000	00010	11011	10000	01011	Others
100,000 or more	93 (79.49)	13 (11.11)	4 (3.42)	2 (1.71)	1 (0.85)	0 (0.00)	4 (3.42)
Body weight status							
Underweight	6 (66.67)	3 (33.33)	0 (0)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Normal weight	159 (71.30)	36 (16.14)	4 (1.79)	11 (4.93)	5 (2.24)	1 (0.45)	7 (3.14)
Overweight	169 (65.00)	45 (17.31)	14 (5.38)	7 (2.69)	5 (1.92)	5 (1.92)	15 (5.77)
Obese	122 (52.59)	68 (29.31)	18 (7.76)	4 (1.72)	5 (2.16)	8 (3.45)	7 (3.02)
Diabetes							
No	424 (67.30)	115 (18.25)	34 (5.40)	10 (1.59)	10 (1.59)	9 (1.43)	28 (4.44)
Yes	21 (34.43)	32 (52.46)	2 (3.28)	0 (0.00)	5 (8.20)	0 (0.00)	1 (1.64)
Osteoarthritis							
No	431 (71.59)	94 (15.61)	27 (4.49)	8 (1.33)	9 (1.50)	8 (1.33)	25 (4.15)
Yes	13 (16.25)	50 (62.50)	6 (7.50)	2 (2.50)	5 (6.25)	1 (1.25)	3 (3.75)
Spinal cord injury							
No	443 (65.44)	137 (20.24)	35 (5.17)	10 (1.48)	15 (2.22)	9 (1.33)	28 (4.14)
Yes	2 (14.29)	10 (71.43)	1 (7.14)	0 (0.00)	0 (0.00)	0 (0.00)	1 (7.14)
Stroke							
No	439 (65.33)	138 (20.54)	34 (5.06)	10 (1.49)	15 (2.23)	9 (1.34)	27 (4.02)
Yes	5 (27.78)	9 (50.00)	2 (11.11)	0 (0.00)	0 (0.00)	0 (0.00)	2 (11.11)
Multiple sclerosis							
No	444 (64.53)	145 (21.08)	36 (5.23)	10 (1.45)	15 (2.18)	9 (1.31)	29 (4.22)
Yes	1 (33.33)	2 (66.67)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Parkinson's disease							
No	445 (64.49)	146 (21.16)	36 (5.22)	10 (1.45)	15 (2.17)	9 (1.30)	29 (4.2)
Yes	0 (0.00)	1 (100.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Rheumatoid arthritis							
No	414 (74.86)	74 (13.38)	21 (3.80)	8 (1.45)	6 (1.08)	6 (1.08)	24 (4.34)
Yes	30 (21.90)	73 (53.28)	15 (10.95)	2 (1.46)	9 (6.57)	3 (2.19)	5 (3.65)
Asthma							
No	399 (66.95)	113 (18.96)	28 (4.70)	10 (1.68)	14 (2.35)	9 (1.51)	23 (3.86)
Yes	45 (47.87)	34 (36.17)	8 (8.51)	0 (0.00)	1 (1.06)	0 (0.00)	6 (6.38)
Cancer							
No	431 (66.82)	125 (19.38)	31 (4.81)	10 (1.55)	14 (2.17)	7 (1.09)	27 (4.19)
Yes	14 (30.43)	22 (47.83)	5 (10.87)	0 (0.00)	1 (2.17)	2 (4.35)	2 (4.35)
Depression							
No	368 (67.77)	97 (17.86)	27 (4.97)	6 (1.10)	14 (2.58)	7 (1.29)	24 (4.42)
Yes	77 (52.03)	50 (33.78)	9 (6.08)	4 (2.70)	1 (0.68)	2 (1.35)	5 (3.38)
Heart attack							
No	438 (66.36)	129 (19.55)	35 (5.30)	9 (1.36)	13 (1.97)	9 (1.36)	27 (4.09)
Yes	6 (20.00)	18 (60.00)	1 (3.33)	1 (3.33)	2 (6.67)	0 (0.00)	2 (6.67)
Heart failure							
No	440 (65.48)	133 (19.79)	36 (5.36)	10 (1.49)	15 (2.23)	9 (1.34)	29 (4.32)
Yes	4 (22.22)	14 (77.78)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Hypertension							
No	351 (75.48)	59 (12.69)	21 (4.52)	8 (1.72)	4 (0.86)	4 (0.86)	18 (3.87)
Yes	93 (41.33)	88 (39.11)	15 (6.67)	2 (0.89)	11 (4.89)	5 (2.22)	11 (4.89)
Lung disease							
No	439 (67.54)	121 (18.62)	30 (4.62)	10 (1.54)	15 (2.31)	9 (1.38)	26 (4.00)
Yes	6 (14.63)	26 (63.41)	6 (14.63)	0 (0.00)	0 (0.00)	0 (0.00)	3 (7.32)

Note: Others includes profiles 11010, 10011, 10001, 10110, 11100, 00011, 01000, 10010, 10111, 11110.

Table 19

Descriptive Statistics (N, %) for all Participants of PROMIS Across the Number of Physical Fitness Trait Deficiencies

Individual characteristics	Number of physical fitness deficiency					
	0	1	2	3	4	5
Total	458 (62.91)	24 (3.30)	35 (4.81)	5 (0.69)	52 (7.14)	154 (21.15)
Sex						
Men	236 (65.74)	11 (3.06)	19 (5.29)	3 (0.84)	28 (7.80)	62 (17.27)
Women	222 (60.16)	13 (3.52)	16 (4.34)	2 (0.54)	24 (6.50)	92 (24.93)
Age						
18-39	219 (84.23)	9 (3.46)	6 (2.31)	1 (0.38)	8 (3.08)	17 (6.54)
40-59	158 (63.2)	4 (1.60)	9 (3.60)	1 (0.40)	16 (6.40)	62 (24.80)
Above 60	80 (37.04)	10 (4.63)	20 (9.26)	3 (1.39)	28 (12.96)	75 (34.72)
Education						
Less than high school	4 (33.33)	0 (0.00)	0 (0.00)	1 (8.33)	5 (41.67)	2 (16.67)
High school grad	85 (57.05)	5 (3.36)	9 (6.04)	0 (0.00)	10 (6.71)	40 (26.85)
More than high school	368 (65.13)	18 (3.19)	26 (4.6)	4 (0.71)	37 (6.55)	112 (19.82)
Race						
White	343 (60.92)	17 (3.02)	29 (5.15)	4 (0.71)	46 (8.17)	124 (22.02)
Black	56 (71.79)	4 (5.13)	2 (2.56)	0 (0.00)	3 (3.85)	13 (16.67)
Asian	4 (100.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
American Indian/Alaska Native	2 (66.67)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (33.33)
Other	53 (66.25)	3 (3.75)	4 (5.00)	1 (1.25)	3 (3.75)	16 (20.00)
Marital status						
Never Married	133 (82.10)	7 (4.32)	5 (3.09)	1 (0.62)	4 (2.47)	12 (7.41)
Married	269 (59.25)	14 (3.08)	23 (5.07)	4 (0.88)	36 (7.93)	108 (23.79)
Others	56 (50.00)	3 (2.68)	7 (6.25)	0 (0.00)	12 (10.71)	34 (30.36)
Family income						
Less than \$20,000	41 (51.25)	6 (7.50)	5 (6.25)	0 (0.00)	7 (8.75)	21 (26.25)
\$20,000 - \$49,999	132 (53.44)	7 (2.83)	13 (5.26)	1 (0.40)	24 (9.72)	70 (28.34)
\$50,000 - \$99,999	189 (70.00)	8 (2.96)	14 (5.19)	2 (0.74)	14 (5.19)	43 (15.93)
100,000 or more	93 (79.49)	2 (1.71)	3 (2.56)	1 (0.85)	5 (4.27)	13 (11.11)
Body weight status						
Underweight	6 (66.67)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	3 (33.33)
Normal weight	159 (71.30)	12 (5.38)	6 (2.69)	1 (0.45)	9 (4.04)	36 (16.14)
Overweight	169 (65.00)	8 (3.08)	17 (6.54)	1 (0.38)	20 (7.69)	45 (17.31)
Obese	122 (52.59)	4 (1.72)	12 (5.17)	3 (1.29)	23 (9.91)	68 (29.31)
Diabetes						
No	424 (67.30)	12 (1.90)	29 (4.60)	5 (0.79)	45 (7.14)	115 (18.25)
Yes	21 (34.43)	0 (0.00)	1 (1.64)	0 (0.00)	7 (11.48)	32 (52.46)
Osteoarthritis						
No	431 (71.59)	10 (1.66)	25 (4.15)	5 (0.83)	37 (6.15)	94 (15.61)
Yes	13 (16.25)	2 (2.50)	4 (5.00)	0 (0.00)	11 (13.75)	50 (62.50)

Table 19 (cont.)

Individual characteristics	Number of physical fitness deficiency					
	0	1	2	3	4	5
Spinal cord injury						
No	443 (65.44)	12 (1.77)	29 (4.28)	5 (0.74)	51 (7.53)	137 (20.24)
Yes	2 (14.29)	0 (0.00)	1 (7.14)	0 (0.00)	1 (7.14)	10 (71.43)
Stroke						
No	439 (65.33)	12 (1.79)	28 (4.17)	5 (0.74)	50 (7.44)	138 (20.54)
Yes	5 (27.78)	0 (0.00)	2 (11.11)	0 (0.00)	2 (11.11)	9 (50.00)
Multiple sclerosis						
No	444 (64.53)	12 (1.74)	30 (4.36)	5 (0.73)	52 (7.56)	145 (21.08)
Yes	1 (33.33)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	2 (66.67)
Parkinson's disease						
No	445 (64.49)	12 (1.74)	30 (4.35)	5 (0.72)	52 (7.54)	146 (21.16)
Yes	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (100.00)
Rheumatoid Arthritis						
No	414 (74.86)	10 (1.81)	23 (4.16)	4 (0.72)	28 (5.06)	74 (13.38)
Yes	30 (21.90)	2 (1.46)	7 (5.11)	1 (0.73)	24 (17.52)	73 (53.28)
Asthma						
No	399 (66.95)	11 (1.85)	26 (4.36)	4 (0.67)	43 (7.21)	113 (18.96)
Yes	45 (47.87)	1 (1.06)	4 (4.26)	1 (1.06)	9 (9.57)	34 (36.17)
Cancer						
No	431 (66.82)	11 (1.71)	27 (4.19)	5 (0.78)	46 (7.13)	125 (19.38)
Yes	14 (30.43)	1 (2.17)	3 (6.52)	0 (0.00)	6 (13.04)	22 (47.83)
Depression						
No	368 (67.77)	8 (1.47)	23 (4.24)	5 (0.92)	42 (7.73)	97 (17.86)
Yes	77 (52.03)	4 (2.70)	7 (4.73)	0 (0.00)	10 (6.76)	50 (33.78)
Heart attack						
No	438 (66.36)	11 (1.67)	28 (4.24)	5 (0.76)	49 (7.42)	129 (19.55)
Yes	6 (20.00)	1 (3.33)	2 (6.67)	0 (0.00)	3 (10.00)	18 (60.00)
Heart failure						
No	440 (65.48)	12 (1.79)	30 (4.46)	5 (0.74)	52 (7.74)	133 (19.79)
Yes	4 (22.22)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	14 (77.78)
Hypertension						
No	351 (75.48)	9 (1.94)	16 (3.44)	4 (0.86)	26 (5.59)	59 (12.69)
Yes	93 (41.33)	3 (1.33)	14 (6.22)	1 (0.44)	26 (11.56)	88 (39.11)
Lung disease						
No	439 (67.54)	12 (1.85)	27 (4.15)	5 (0.77)	46 (7.08)	121 (18.62)
Yes	6 (14.63)	0 (0.00)	3 (7.32)	0 (0.00)	6 (14.63)	26 (63.41)

Table 20

Prevalence of Profiles Among Muscular Strength, Flexibility, Aerobic Endurance, and Balance

	Muscular strength (%)	
	Deficiency	Sufficiency
Flexibility		
Deficiency	26.24	3.57
Sufficiency	3.16	67.03
Aerobic		
Endurance		
Deficiency	28.30	6.87
Sufficiency	1.10	63.74
Balance		
Deficiency	21.29	2.75
Sufficiency	8.10	67.86

Since muscular strength is an essential component of physical fitness, physical fitness profiles were further analyzed by combining other physical fitness trait statuses with muscular strength status (Table 20). 26.24% of people were found to be deficient in both muscular strength and flexibility. Only a few people have profiles such as ‘10’ (3.57%) or ‘01’ (3.16%) on muscular strength and flexibility. Over a quarter of people (28.3%) were found deficient in both aerobic endurance and muscular strength. At the same time, 6.87% of participants were found to be deficient in aerobic endurance but sufficient in muscular strength. Very few people (1.1%) were deficient in muscular strength but sufficient in aerobic endurance. In contract, very few people (2.75%) were identified to be deficient in balance but sufficient in muscular strength. However, 8.1% of people were recognized to have a deficiency in muscular strength but sufficiency on

balance. Over 21% of participants were found to be deficient in both muscular strength and balance skill.

Trends of Physical Fitness Trait Deficiencies in Aging

Since Table 17 shows a significant bivariate correlation among age and each physical fitness trait status, to explore this relationship more clearly, eight age groups were applied to classify participants into different aging levels. Percentages of participants in each physical fitness trait deficiency were calculated across each diverse age group (Table 21). Despite the fact that a little decrease on the prevalence of muscular strength deficiency from 50-59 to 60-69 age groups, the prevalences of muscular strength deficiency, flexibility deficiency, aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency increased over the age groups overall. For example, the prevalences of muscular strength deficiency and flexibility deficiency increased by 56.39% and 71.1% from 18-29 to 80+ age groups, respectively. Similarly, the prevalences of aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency increased by 69.34%, 61.35% and 70.43% from 18-29 to 80+ age groups, respectively. From a middle age group (40-49) to an older age group (70-79), the prevalences of deficiency in muscular strength, flexibility, and balance increased by nearly 25% and the prevalences of deficiency in aerobic endurance and fine motor skill increased by over 25%.

Similar patterns of physical fitness trait deficiencies in aging were recognized in both male and female groups. Regardless of a little decrease of the prevalences of muscular strength deficiency, flexibility deficiency, balance deficiency, and fine motor skill deficiency from 50-59 to 60-69 age groups among men, the prevalences of muscular strength deficiency, flexibility deficiency, aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency increased over the age groups overall. Men in age 80+ group have the highest percentage of each

physical fitness trait deficiency compared to men in other age groups. Even though the prevalences of all physical fitness traits were slightly decreased from 60-69 to 70-79 age groups among women, in general, the prevalences of muscular strength deficiency, flexibility deficiency, aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency increased over the age groups. Women in age 80+ group have the highest percentage of each physical fitness trait deficiencies compared to women in other age groups. Therefore, as age goes, clear patterns on all physical fitness traits' deficiency were found.

Table 21

Percentage of Each Physical Fitness Trait Deficiency with Aging Among Men and Women

	Muscular strength deficiency	Flexibility deficiency	Aerobic endurance deficiency	Balance deficiency	Fine motor skill deficiency
Age					
18-29	5.37	5.37	10.07	3.36	6.04
30-39	17.12	18.02	21.62	12.61	17.12
40-49	27.36	27.36	31.13	21.70	25.47
50-59	38.89	35.42	38.89	28.47	37.50
60-69	37.50	40.28	54.17	33.33	44.44
70-79	49.09	48.18	56.36	41.82	52.73
80+	61.76	76.47	79.41	64.71	76.47
Men					
18-29	3.17	4.76	6.35	0.00	6.35
30-39	13.73	13.73	19.61	7.84	11.76
40-49	16.95	18.64	22.03	15.25	16.95
50-59	34.85	30.30	34.85	19.70	31.82
60-69	25.71	25.71	42.86	17.14	28.57
70-79	50.79	47.62	53.97	41.27	52.38
80+	63.64	72.73	77.27	59.09	72.73

Table 21 (cont.)

	Muscular strength deficiency	Flexibility deficiency	Aerobic endurance deficiency	Balance deficiency	Fine motor skill deficiency
Women					
18-29	6.98	5.81	12.79	5.81	5.81
30-39	20.00	21.67	23.33	16.67	21.67
40-49	40.43	38.30	42.55	29.79	36.17
50-59	42.31	39.74	42.31	35.90	42.31
60-69	48.65	54.05	64.86	48.65	59.46
70-79	46.81	48.94	59.57	42.55	53.19
80+	58.33	83.33	83.33	75.00	83.33

Figure 7 reports the trends of deficiency in each physical fitness trait as aging. As indicated by the picture, the first physical fitness component starts to be deficient during aging is aerobic endurance and the prevalence of aerobic endurance deficiency is the highest one compared with the other four physical fitness traits among the different age groups. In contrast, balance is the last physical fitness trait to be deficient in regards to aging, and it also has the lowest prevalence of deficiency compared with other four physical fitness traits. Among people 60 years old and younger, all five physical fitness traits have similar deficiency trends as aging. However, muscular strength had an obvious deficiency trend from 60-69 to 70-79 age groups, and similar apparent deficiency trends were happening in other four physical fitness traits from 70-79 to 80+ age groups.

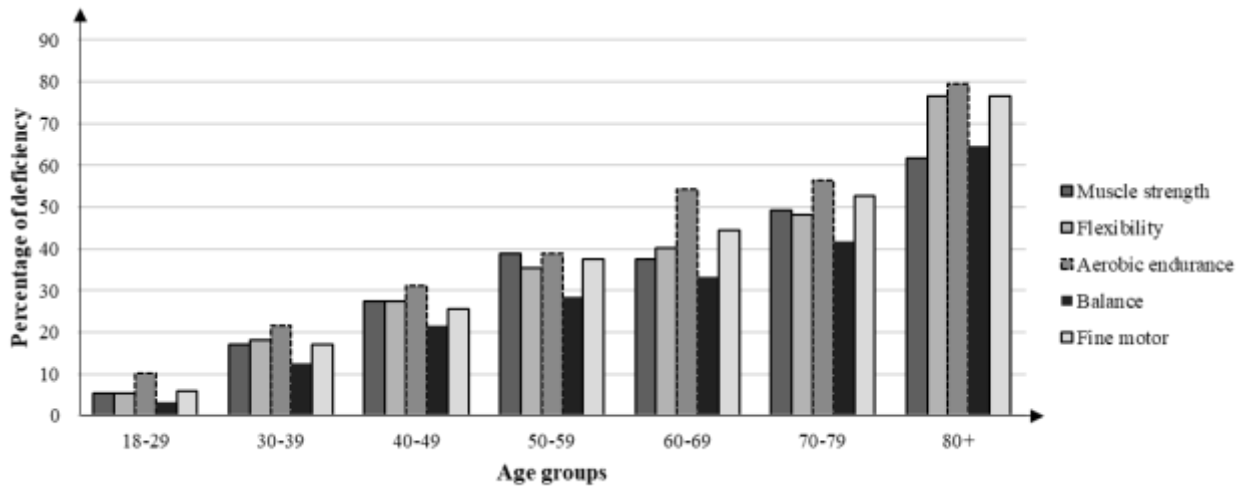


Figure 7. Trends of physical fitness trait deficiencies with aging

Logistic regression models were conducted to estimate the statistical trends of each physical fitness trait deficiency due to aging, along with considering all possible confounding variables, such as sex, race, education level, marital status, family income, body weight status, and health condition such as diabetes, osteoarthritis, spinal cord injury, stroke, multiple sclerosis, Parkinson's disease, rheumatoid arthritis, asthma, cancer, depression, heart attack, heart failure, hypertension, and lung disease. Odds ratios of five physical fitness traits' deficiency across seven age groups were estimated. Meanwhile, logistic regression models were also applied to interpret associations among other demographic characteristics and diseases conditions.

Table 22 reports the estimated odds ratios of physical fitness trait deficiencies in the logistic regressions. After adjusted for individual's characteristics and health conditions, the odds of muscular strength deficiency among people in 70-79 and 80+ age groups were 508% (adjusted odds ratio [AOR] = 5.08; 95% CI = 1.665, 15.512) and 995% (AOR = 9.951; 95% CI = 2.315, 42.774) higher than people aged in 18-29 age group, respectively. Compared with those in people in 18-29 age group, the odds of flexibility deficiency were 552% (AOR = 5.52; 95% CI =

1.853, 16.446) and 1911% (AOR = 19.115; 95% CI = 4.367, 83.672) higher among people in 70-79 and 80+ age groups respectively. The odds of aerobic endurance deficiency were 652% (AOR = 6.525; 95% CI = 2.365, 18.007) and 2144% (AOR = 21.441; 95% CI = 5.077, 90.557) higher among people in 70-79 and 80+ age groups than people in 18-29 age group, respectively. Similar patterns were also identified on both balance deficiency and fine motor skill deficiency. The odds of balance deficiency were 706% (AOR = 7.061; 95% CI = 1.984, 25.132) and 1511% (AOR = 15.117; 95% CI = 3.104, 73.617) higher among people in 70-79 and 80+ age groups and the odds of fine motor skill deficiency were 659% (AOR = 6.592; 95% CI = 2.268, 19.159) and 2211% (AOR = 22.114; 95% CI = 5.011, 97.593) higher among people in 70-79 and 80+ age groups than people in 18-29 age group, respectively. Trends of muscular strength deficiency, flexibility deficiency, aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency while aging were verified by multiple logistic regression models.

Table 22

Adjusted Odds Ratios (95% CI) of Physical Fitness Trait Deficiencies from Multiple Logistic Regression Models

Individual characteristics	Muscular strength Deficiency	Flexibility Deficiency	Aerobic endurance deficiency	Balance deficiency	Fine motor skill deficiency
Age					
18-29	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)
30-39	2.299 (0.791, 6.681)	2.055 (0.724, 5.832)	2.562 (0.998, 6.578)	2.453 (0.710, 8.481)	1.939 (0.696, 5.408)
40-49	4.832 (1.710, 13.655)	3.969 (1.418, 11.104)	4.335 (1.688, 11.132)	4.817 (1.423, 16.307)	3.386 (1.227, 9.347)
50-59	6.265 (2.246, 17.478)	3.907 (1.419, 10.758)	4.059 (1.588, 10.372)	4.152 (1.255, 13.742)	4.251 (1.572, 11.498)
60-69	3.476 (1.092, 11.064)	3.779 (1.224, 11.662)	6.434 (2.282, 18.137)	4.150 (1.127, 15.288)	4.658 (1.554, 13.962)
70-79	5.083 (1.665, 15.512)	5.520 (1.853, 16.446)	6.525 (2.365, 18.007)	7.061 (1.984, 25.132)	6.592 (2.268, 19.159)
80+	9.951 (2.315, 42.774)	19.115 (4.367, 83.672)	21.441 (5.077, 90.557)	15.117 (3.104, 73.617)	22.114 (5.011, 97.593)
Sex					
Women	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)
Men	0.602 (0.371, 0.977)	0.515 (0.316, 0.840)	0.635 (0.400, 1.008)	0.373 (0.219, 0.637)	0.509 (0.314, 0.824)
Race					
Other	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)
White	0.733 (0.354, 1.519)	0.705 (0.339, 1.464)	0.629 (0.317, 1.249)	0.514 (0.236, 1.117)	0.754 (0.368, 1.545)
Black	0.660 (0.226, 1.923)	0.667 (0.228, 1.95)	0.625 (0.231, 1.692)	0.466 (0.140, 1.551)	0.601 (0.208, 1.736)
Asian	N/A	N/A	N/A	N/A	N/A
American Indian/ Alaska Native	12.741 (0.696, 233.333)	11.254 (0.495, 255.954)	6.074 (0.333, 110.775)	14.026 (0.501, 392.311)	12.007 (0.605, 238.19)
Education					
More than high school	1 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)
Less than high school	1.340 (0.241, 7.458)	6.436 (0.930, 44.559)	4.850 (0.789, 29.825)	0.747 (0.134, 4.162)	2.488 (0.429, 14.436)
High school grad	0.782 (0.441, 1.387)	0.683 (0.380, 1.226)	0.969 (0.560, 1.676)	0.943 (0.516, 1.724)	0.798 (0.450, 1.418)

Table 22 (cont.)

Individual characteristics	Muscular strength Deficiency	Flexibility Deficiency	Aerobic endurance deficiency	Balance deficiency	Fine motor skill deficiency
Marital status					
Others (e.g. divorced)	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)
Never Married	0.645 (0.236, 1.761)	0.510 (0.184, 1.413)	0.799 (0.322, 1.987)	0.496 (0.165, 1.493)	0.562 (0.209, 1.511)
Married	2.253 (1.172, 4.331)	2.323 (1.209, 4.464)	2.097 (1.115, 3.944)	1.678 (0.852, 3.306)	1.843 (0.970, 3.501)
Family income					
100,000 or more	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)
Less than \$20,000	10.556 (3.508, 31.759)	5.100 (1.723, 15.095)	7.987 (2.821, 22.608)	4.945 (1.560, 15.683)	4.727 (1.669, 13.387)
\$20,000 - \$49,999	3.909 (1.785, 8.560)	3.873 (1.805, 8.310)	4.202 (1.996, 8.846)	4.497 (1.917, 10.551)	2.917 (1.403, 6.066)
\$50,000 - \$99,999	1.989 (0.929, 4.257)	1.440 (0.684, 3.033)	1.799 (0.871, 3.714)	1.955 (0.837, 4.565)	1.238 (0.603, 2.542)
Body weight					
Underweight	6.341 (1.083, 37.111)	5.964 (0.997, 35.699)	3.828 (0.700, 20.924)	5.570 (0.885, 35.073)	4.502 (0.773, 26.215)
Normal weight	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)
Overweight	1.432 (0.751, 2.731)	1.170 (0.617, 2.219)	0.974 (0.536, 1.769)	0.870 (0.443, 1.709)	1.340 (0.717, 2.504)
Obese	3.401 (1.781, 6.492)	2.852 (1.506, 5.401)	2.151 (1.185, 3.901)	1.710 (0.878, 3.330)	2.409 (1.282, 4.528)
Diabetes	1.905 (0.903, 4.020)	3.068 (1.419, 6.633)	2.063 (0.965, 4.407)	5.454 (2.472, 12.031)	2.881 (1.343, 6.182)
Osteoarthritis	2.412 (0.934, 6.226)	3.202 (1.206, 8.502)	3.903 (1.423, 10.702)	2.358 (0.925, 6.011)	3.302 (1.228, 8.879)
Spinal cord injury	2.524 (0.431, 14.773)	2.108 (0.365, 12.180)	1.579 (0.281, 8.864)	3.070 (0.569, 16.570)	3.480 (0.503, 24.087)
Stroke	0.879 (0.207, 3.732)	0.500 (0.120, 2.083)	0.437 (0.105, 1.812)	0.552 (0.133, 2.287)	0.889 (0.201, 3.939)
Multiple sclerosis	5.910 (0.433, 80.723)	5.385 (0.353, 82.168)	4.824 (0.324, 71.811)	10.69 (0.660, 173.220)	5.165 (0.373, 71.531)
Parkinson's disease	N/A	N/A	N/A	N/A	N/A
Rheumatoid arthritis	3.392 (1.588, 7.243)	3.052 (1.422, 6.549)	2.812 (1.319, 5.997)	3.190 (1.491, 6.826)	2.536 (1.189, 5.405)
Asthma	2.057 (1.034, 4.093)	1.672 (0.826, 3.384)	1.210 (0.606, 2.418)	1.820 (0.890, 3.719)	2.230 (1.127, 4.412)
Cancer	4.644 (1.967, 10.968)	2.077 (0.884, 4.876)	2.094 (0.877, 5.002)	1.533 (0.644, 3.647)	1.849 (0.780, 4.381)
Depression	1.992 (1.140, 3.481)	2.062 (1.183, 3.595)	2.367 (1.394, 4.019)	1.895 (1.051, 3.415)	2.025 (1.163, 3.525)

Table 22 (*cont.*)

Individual characteristics	Muscular strength		Aerobic endurance		
	Deficiency	Flexibility Deficiency	deficiency	Balance deficiency	Fine motor skill deficiency
Heart attack	1.498 (0.524, 4.284)	1.920 (0.662, 5.57)	2.620 (0.861, 7.970)	2.992 (1.053, 8.504)	2.166 (0.732, 6.415)
Heart failure	1.861 (0.462, 7.494)	1.809 (0.451, 7.249)	1.219 (0.303, 4.902)	2.787 (0.689, 11.272)	1.421 (0.351, 5.747)
Hypertension	1.492 (0.898, 2.480)	1.661 (0.993, 2.776)	1.882 (1.149, 3.084)	1.877 (1.091, 3.228)	1.753 (1.057, 2.909)
Lung disease	6.647 (2.292, 19.273)	4.209 (1.543, 11.48)	2.983 (1.090, 8.158)	2.927 (1.165, 7.354)	5.721 (1.941, 16.868)

Association Between Physical Fitness Trait Deficiencies and Body Weight Status

Table 23 reports participants' percentages on each physical fitness trait deficiency across different body weight status. Regarding the 33.33% prevalence of all physical fitness trait deficiencies in the underweight group, the underweight group cannot be compared with the other three body weight groups due to the limited sample size ($n = 14$) of the underweight group. Therefore, comparisons among normal weight, overweight, and obese groups were performed. The prevalences of muscular strength deficiency, flexibility deficiency, aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency increased from normal weight group to overweight and obese groups. For example, the prevalences of muscular strength deficiency and flexibility deficiency increased by 22.53% and 19.86% from normal weight to obese groups, respectively. Similarly, the prevalences of aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency increased by 19.64%, 13.94% and 17.22% from normal weight to obese groups, respectively.

Table 23

Prevalence (N, %) of Physical Fitness Trait Deficiencies Across Body Weight Status

Body weight status	Muscular strength deficiency	Flexibility deficiency	Aerobic endurance deficiency	Balance deficiency	Fine motor skill deficiency
Underweight	3 (33.33)	3 (33.33)	3 (33.33)	3 (33.33)	3 (33.33)
Normal weight	43 (19.28)	48 (21.52)	60 (26.91)	41 (18.39)	51 (22.87)
Overweight	69 (26.54)	68 (26.15)	83 (31.92)	54 (20.77)	76 (29.23)
Obese	97 (41.81)	96 (41.38)	108 (46.55)	75 (32.33)	93 (40.09)

Table 24 reports the adjusted odds ratios of all physical fitness trait deficiencies among body weight status. After adjusting for individual characteristics and health conditions, the odds

of muscular strength deficiency among obese people were 340% (AOR =3.401; 95% CI = 1.781, 6.492) higher than normal weight people. Similar patterns were identified on flexibility deficiency and aerobic endurance deficiency. The odds of flexibility deficiency and aerobic endurance deficiency were 285% (AOR = 2.852; 95% CI = 1.506, 5.401) and 215% (AOR = 2.151; 95% CI = 1.185, 3.901) higher among obese people than normal weight people. Compared with their normal weight counterparts, the odds of fine motor skill deficiency was 241% (AOR = 2.409; 95% CI = 1.282, 4.528) higher among obese people. Only the odds of balance deficiency was not significant higher in the obese group compared with normal weight group.

Association Between Physical Fitness Trait Deficiencies and Chronic Diseases

To evaluate the associations between physical fitness trait deficiencies and chronic diseases, the prevalence of each chronic disease among participants in PROMIS Wave I study was first estimated. Table 24 reports that nearly 10% of participants have diabetes, and over 10% of participants have osteoarthritis and asthma. Over 33% of participants have hypertension. Over 20% of participants have depression and rheumatoid arthritis. Nearly 6% of participants have been diagnosed with lung disease and over 7% of participants have cancer. Only a few participants have been told having a spinal cord injury (2%), stroke (2.89%), multiple sclerosis (0.44%), Parkinson's disease (0.11%), heart attack (4.34%), and heart failure (2.78%).

In addition, Table 24 shows the percentages of each physical fitness trait deficiency among people with specific diseases. Compared to their counterparts without multiple sclerosis or Parkinson's disease, people with multiple sclerosis or Parkinson's disease have higher prevalences of muscular strength deficiency, flexibility deficiency, aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency. Whereas, these patterns were not significant

due to a small number of people with multiple sclerosis or Parkinson's diseases in this study. Compared to their counterparts without diabetes, osteoarthritis, spinal cord injury, stroke, rheumatoid arthritis, asthma, cancer, depression, heart attack, heart failure, hypertension, or lung disease, the prevalences of muscular strength deficiency, flexibility deficiency, aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency were significantly higher among people with diabetes, osteoarthritis, spinal cord injury, stroke, rheumatoid arthritis, asthma, cancer, depression, heart attack, heart failure, hypertension, and lung disease.

Table 24

Prevalence (N, %) of Each Physical Fitness Trait Deficiency Across Disease Groups

Diseases status		Total	Muscular strength deficiency	Flexibility deficiency	Aerobic endurance deficiency	Balance deficiency	Fine motor skill deficiency
Diabetes	No	815 (90.56)	168 (26.67)	171 (27.14)	193 (30.63)	130 (20.63)	178 (28.25)
	Yes	85 (9.44)	34 (55.74)*	39 (63.93)*	39 (63.93) *	38 (62.30) *	40 (65.57) *
Osteoarthritis	No	769 (86.99)	137 (22.76)	141 (23.42)	159 (26.41)	109 (18.11)	147 (24.42)
	Yes	115 (13.01)	58 (72.50)*	62 (77.50)*	66 (82.50) *	55 (68.75) *	63 (78.75) *
Spinal cord injury	No	882 (98.00)	191 (28.21)	199 (29.39)	221 (32.64)	157 (23.19)	206 (30.43)
	Yes	18 (2.00)	11 (78.57)*	11 (78.57)*	11 (78.57) *	11 (78.57) *	12 (85.71) *
Stroke	No	873 (97.11)	190 (28.27)	199 (29.61)	221 (32.89)	158 (23.51)	205 (30.51)
	Yes	26 (2.89)	12 (66.67)*	11 (61.11)*	11 (61.11) *	10 (55.56) *	13 (72.22) *
Multiple sclerosis	No	896 (99.56)	200 (29.07)	208 (30.23)	230 (33.43)	166 (24.13)	216 (31.4)
	Yes	4 (0.44)	2 (66.67)	2 (66.67)	2 (66.67)	2 (66.67)	2 (66.67)
Parkinson's disease	No	899 (99.89)	201 (29.13)	209 (30.29)	231 (33.48)	167 (24.2)	217 (31.45)
	Yes	1 (0.11)	1 (100.00)	1 (100.00)	1 (100.00)	1 (100.00)	1 (100.00)
Rheumatoid arthritis	No	701 (77.98)	109 (19.71)	111 (20.07)	127 (22.97)	85 (15.37)	118 (21.34)
	Yes	198 (22.02)	93 (67.88)*	99 (72.26) *	105 (76.64) *	83 (60.58) *	100 (72.99) *
Asthma	No	783 (87.10)	157 (26.34)	166 (27.85)	188 (31.54)	131 (21.98)	170 (28.52)
	Yes	116 (12.90)	45 (47.87)*	44 (46.81) *	44 (46.81) *	37 (39.36) *	48 (51.06) *
Cancer	No	834 (92.67)	172 (26.67)	181 (28.06)	202 (31.32)	145 (22.48)	189 (29.30)
	Yes	66 (7.33)	30 (65.22)*	29 (63.04) *	30 (65.22) *	23 (50.00) *	29 (63.04) *

Table 24 (cont.)

Diseases status		Total	Muscular strength deficiency	Flexibility deficiency	Aerobic endurance deficiency	Balance deficiency	Fine motor skill deficiency
Depression	No	713 (79.22)	140 (25.78)	148 (27.26)	162 (29.83)	117 (21.55)	155 (28.55)
	Yes	187 (20.78)	62 (41.89)*	62 (41.89) *	70 (47.30) *	51 (34.46) *	63 (42.57) *
Heart attack	No	860 (95.66)	182 (27.58)	189 (28.64)	209 (31.67)	148 (22.42)	195 (29.55)
	Yes	39 (4.34)	20 (66.67)*	21 (70.00) *	23 (76.67) *	20 (66.67) *	23 (76.67) *
Heart failure	No	874 (97.22)	188 (27.98)	196 (29.17)	218 (32.44)	154 (22.92)	204 (30.36)
	Yes	25 (2.78)	14 (77.78)*	14 (77.78) *	14 (77.78) *	14 (77.78) *	14 (77.78) *
Hypertension	No	595 (66.18)	92 (19.78)	93 (20.00)	104 (22.37)	68 (14.62)	95 (20.43)
	Yes	304 (33.82)	110 (48.89)*	117 (52.00) *	128 (56.89) *	100 (44.44) *	123 (54.67) *
Lung disease	No	847 (94.11)	168 (25.85)	178 (27.38)	200 (30.77)	141 (21.69)	183 (28.15)
	Yes	53 (5.89)	34 (82.93)*	32 (78.05) *	32 (78.05) *	27 (65.85) *	35 (85.37) *

Note: * represents $p < 0.05$ in chi-square test.

According to Table 22 about the estimated odds ratios of physical fitness trait deficiencies across each chronic disease, no significant association was found among physical fitness traits' deficiency with spinal cord injury disease, stroke, multiple sclerosis, Parkinson's disease, and heart failure due to lacking data on people with those diseases. Except for above the diseases, other chronic diseases were found to have associations with some or all physical fitness trait deficiencies. For example, compared with people without diabetes, people with diabetes had higher odds of flexibility deficiency (AOR = 3.068; 95% CI = 1.419, 6.633), balance deficiency (AOR = 5.454; 95% CI = 2.472, 12.031), and fine motor skill deficiency (AOR = 2.881; 95% CI = 1.343, 6.182). Among those associations, balance deficiency had the highest effect size on odds ratio. People with osteoarthritis had higher odds of flexibility deficiency (AOR = 3.202; 95% CI = 1.206, 8.502), aerobic endurance deficiency (AOR = 3.903; 95% CI = 1.423, 10.702), and fine motor skill deficiency (AOR = 3.302; 95% CI = 1.228, 8.879) than those without osteoarthritis. Among those associations, aerobic endurance deficiency was found as the highest effect size on odds ratio compared to the other two physical fitness traits.

Regarding people with rheumatoid arthritis, they were found having significant higher odds on muscular strength deficiency (AOR = 3.392; 95% CI = 1.588, 7.243), flexibility deficiency (AOR = 3.052; 95% CI = 1.422, 6.549), aerobic endurance deficiency (AOR = 2.812; 95% CI = 1.319, 5.997), balance deficiency (AOR = 3.190; 95% CI = 1.491, 6.826), and fine motor skill deficiency (AOR = 2.536; 95% CI = 1.189, 5.405) compared with people without rheumatoid arthritis. Among those associations, muscular strength was identified to have the highest odds ratio compared with other four physical fitness traits.

People with asthma were found to have significant associations with muscular strength deficiency (AOR = 2.057; 95% CI = 1.034, 4.093) and fine motor skill deficiency (AOR = 2.23; 95% CI = 1.127, 4.412). The odds of muscular strength among people with cancer were 464% (AOR = 4.644; 95% CI = 1.967, 10.968) higher than people without cancer. People with heart attack were identified to have a significant association with balance deficiency (AOR = 2.992; 95% CI = 1.053, 8.504).

People with depression were found to have significant higher odds on muscular strength deficiency (AOR = 1.992; 95% CI = 1.14, 3.481), flexibility deficiency (AOR = 2.062; 95% CI = 1.183, 3.595), aerobic endurance deficiency (AOR = 2.367; 95% CI = 1.394, 4.019), balance deficiency (AOR = 1.895; 95% CI = 1.051, 3.415), and fine motor skill deficiency (AOR = 2.025; 95% CI = 1.163, 3.525) compared with people without depression. Hypertension was found significant relationships with aerobic endurance deficiency (AOR = 1.882; 95% CI = 1.149, 3.084), balance deficiency (AOR = 1.877; 95% CI = 1.091, 3.228), and fine motor skill deficiency (AOR = 1.753; 95% CI = 1.057, 2.909).

People with lung disease were observed to have significant higher odds on muscular strength deficiency (AOR = 6.647; 95% CI = 2.292, 19.273), flexibility deficiency (AOR =

4.209; 95% CI = 1.543, 11.48), aerobic endurance deficiency (AOR = 2.983; 95% CI = 1.09, 8.158), balance deficiency (AOR = 2.927; 95% CI = 1.165, 7.354), and fine motor skill deficiency (AOR = 5.721; 95% CI = 1.941, 16.868) compared with people without lung disease. Among those associations, muscular strength deficiency had the highest effect size on odds ratio compared with other four physical fitness traits.

Physical Fitness Traits Among Cardiometabolic, Musculoskeletal and Respiratory Disease

In order to analyze the association of types of chronic diseases with physical fitness trait deficiencies, several chronic diseases were combined. Participants with chronic conditions were classified as a) only cardiometabolic (diabetes, stroke, heart attack, heart failure, or hypertension); b) only musculoskeletal (osteoarthritis, spinal cord injury, or rheumatoid arthritis); c) only respiratory (asthma or lung disease); d) cardiometabolic and musculoskeletal; e) cardiometabolic and respiratory; f) musculoskeletal and respiratory; g) cardiometabolic, musculoskeletal, and respiratory. Several chronic conditions such as multiple sclerosis, Parkinson's disease, cancer, and depression, were ignored due to small sample sizes (less than 20 participants) or not appropriate for the above classification (Vyas, Pan, & Sambamoorthi, 2012).

Table 25 reports the prevalence of each physical fitness trait deficiency across cardiometabolic disease, musculoskeletal disease, and respiratory disease. Obvious increasing patterns were found that the prevalence of each physical fitness trait deficiency increased as the number of diseases compounded. Compared to people with cardiometabolic disease, people with musculoskeletal disease had higher prevalences of muscular strength deficiency (58.33% vs. 35.07%), flexibility deficiency (61.11% vs. 36.57%), aerobic endurance deficiency (66.67% vs. 41.79%), balance deficiency (44.44% vs. 29.85%), and fine motor skill deficiency (55.56% vs. 37.31%). Among people with only one of these three classifications of disease, people with

respiratory had the lowest prevalence of physical fitness trait deficiencies. People with two classifications of chronic disease had higher prevalences of these five physical fitness trait deficiencies than people with only one type of chronic disease. For example, compared to people with only respiratory disease, people with musculoskeletal and respiratory diseases had much higher prevalences of muscular strength deficiency (76.92% vs. 31.11%), flexibility deficiency (76.92% vs. 28.89%), aerobic endurance deficiency (76.92% vs. 28.89%), balance deficiency (53.85% vs. 20.00%), and fine motor skill deficiency (76.92% vs. 31.11%), respectively. Among all people, people with all three types of chronic disease had the highest prevalences of muscular strength deficiency (90.63%), flexibility deficiency (87.50%), aerobic endurance deficiency (87.50%), balance deficiency (75.00%), and fine motor skill deficiency (90.63%).

Table 26 reports the adjusted odds ratios for each physical fitness trait deficiency across cardiometabolic, musculoskeletal, and respiratory diseases. Regarding people with musculoskeletal, they were found to have significantly higher odds on muscular strength deficiency (AOR = 12.117; 95% CI = 5.048,29.083), flexibility deficiency (AOR = 12.051; 95% CI = 4.93,29.454), aerobic endurance deficiency (AOR = 10.762; 95% CI = 4.464,25.945), balance deficiency (AOR = 10.806; 95% CI = 4.248,27.491), and fine motor skill deficiency (AOR = 8.653; 95% CI = 3.661,20.448) compared with people without these three types of chronic disease. Among those associations, muscular strength has the highest odds ratio compared with other four physical fitness traits. Moreover, people with only cardiometabolic or respiratory were also found to have significant higher odds of all five physical fitness trait deficiencies when compared with people without these three types of chronic disease. Similarly, people with musculoskeletal had the highest odds ratios among those associations compared with people with cardiometabolic or respiratory diseases. Compared to those without musculoskeletal,

cardiometabolic, and respiratory diseases, the odds of muscular deficiency (AOR = 56.809; 95% CI = 14.843,217.424), flexibility deficiency(AOR = 38.872; 95% CI = 11.442,132.064), aerobic endurance deficiency(AOR = 23.753; 95% CI = 7.258,77.732), balance deficiency(AOR = 38.016; 95% CI = 12.818,112.752) and fine motor skill deficiency(AOR = 44.022; 95% CI = 11.628,166.654) were 5680%, 3887%, 2375%, 3801%, and 4402% higher among people with musculoskeletal, cardiometabolic, and respiratory diseases, respectively.

Table 25

Prevalence (%) of Each Physical Fitness Trait Deficiency Across Cardiometabolic, Musculoskeletal, and Respiratory Diseases

Chronic diseases	Muscular strength deficiency	Flexibility deficiency	Aerobic endurance deficiency	Balance deficiency	Fine motor skill deficiency
No disease	8.88	9.17	11.83	5.33	9.47
Cardiometabolic	35.07	36.57	41.79	29.85	37.31
Musculoskeletal	58.33	61.11	66.67	44.44	55.56
Respiratory	31.11	28.89	28.89	20.00	31.11
Cardiometabolic and musculoskeletal	59.68	69.35	75.81	66.13	74.19
Cardiometabolic and respiratory	46.67	46.67	46.67	43.33	56.67
Musculoskeletal and respiratory	76.92	76.92	76.92	53.85	76.92
Cardiometabolic, musculoskeletal and respiratory	90.63	87.50	87.50	75.00	90.63

Table 26

Adjusted Odds Ratios of Each Physical Fitness Trait Deficiency Across Cardiometabolic, Musculoskeletal, and Respiratory Diseases

Chronic diseases	Muscular strength deficiency	Flexibility deficiency	Aerobic endurance deficiency	Balance deficiency	Fine motor skill deficiency
No disease	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)
Cardiometabolic	3.066 (1.652, 5.691)	3.246 (1.738, 6.061)	3.022 (1.697, 5.381)	4.708 (2.283, 9.708)	2.854 (1.552, 5.250)
Musculoskeletal	12.117 (5.048, 29.083)	12.051 (4.930, 29.454)	10.762 (4.464, 25.945)	10.806 (4.248, 27.491)	8.653 (3.661, 20.448)
Respiratory	4.435 (1.875, 10.491)	3.784 (1.558, 9.190)	2.520 (1.081, 5.875)	3.979 (1.451, 10.908)	3.837 (1.638, 8.990)
Cardiometabolic and musculoskeletal	10.211 (4.617, 22.581)	15.144 (6.659, 34.444)	14.739 (6.497, 33.435)	26.554 (10.975, 64.250)	15.917 (6.946, 36.471)
Cardiometabolic and respiratory	7.135 (2.788, 18.257)	6.481 (2.506, 16.759)	4.290 (1.694, 10.864)	12.561 (4.587, 34.392)	9.226 (3.552, 23.961)
Musculoskeletal and respiratory	16.539 (3.879, 70.524)	17.363 (3.945, 76.421)	12.373 (2.860, 53.524)	8.899 (2.308, 34.305)	15.035 (3.552, 63.649)
Cardiometabolic, musculoskeletal, and respiratory	56.809 (14.843, 217.424)	38.872 (11.442, 132.064)	23.753 (7.258, 77.732)	38.016 (12.818, 112.752)	44.022 (11.628, 166.654)

Note: Multiple logistic regression models were adjusted on age groups, sex, race, education, marital status, family income, and body weight status.

Physical Fitness Traits in Healthy and Unhealthy Groups

To comprehensively estimate the prevalences of physical fitness trait deficiencies for people with chronic diseases and reveal the relationship of health status with physical fitness trait deficiencies, a new variable “health status” based on the number of chronic diseases was created. Unhealthy status was defined by people with 1 or more chronic conditions including diabetes, osteoarthritis, asthma, hypertension, depression, rheumatoid arthritis, lung disease, cancer, spinal cord injury disease, stroke, multiple sclerosis, Parkinson’s disease, heart attack, and heart failure. Healthy status was defined by participants’ responses that never had a doctor diagnosis as having had any one of above diseases.

The prevalences of physical fitness trait deficiencies among healthy and unhealthy subgroups were compared. Table 27 reports that people with unhealthy status had 38.7% and 38.46% higher prevalences of aerobic endurance and fine motor skill deficiencies compared with their healthy status counterparts. Flexibility was also found to have had a large percentage deficiency (44.71%) in the unhealthy group compared to the healthy group. Furthermore, people with unhealthy status had 34.7% and 32.2% higher prevalence on muscular strength deficiency and balance deficiency.

Table 27

Prevalence (%) of Physical Fitness Trait Deficiencies Across Healthy and Unhealthy Groups

Health status	Muscular strength deficiency	Flexibility deficiency	Aerobic endurance deficiency	Balance deficiency	Fine motor skill deficiency
Healthy	7.89	7.52	9.77	4.51	7.89
Unhealthy	42.59	44.71	48.47	36.71	46.35

According to the results of multivariate logistic regressions, the odds ratios of physical fitness trait deficiencies in the unhealthy subgroup was estimated. Individual characteristics were included as confounding variables in all logistic regressions. People in the unhealthy subgroup were found to have significantly higher odds on muscular strength deficiency (AOR = 5.205; 95% CI = 3.005, 9.015), flexibility deficiency (AOR = 5.865; 95% CI = 3.322, 10.356), aerobic endurance deficiency (AOR = 5.159; 95% CI = 3.087, 8.623), balance deficiency (AOR = 7.444; 95% CI = 3.749, 14.781), and fine motor skill deficiency (AOR = 5.708; 95% CI = 3.294, 9.89) comparing with people in the healthy subgroup. Among those significant associations, balance deficiency had the highest effect size on odds ratio compared with other four physical fitness traits.

Table 28

Adjusted Odds Ratios of Each Physical Fitness Trait Deficiency Across Healthy and Unhealthy Groups

Health status	Muscular strength deficiency	Flexibility deficiency	Aerobic endurance deficiency	Balance deficiency	Fine motor skill deficiency
Healthy	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)	1.000 (reference)
Unhealthy	5.205 (3.005, 9.015)	5.865 (3.322, 10.356)	5.159 (3.087, 8.623)	7.444 (3.749, 14.781)	5.708 (3.294, 9.890)

Physical Function Scores and Diagnosed Physical Fitness Trait Deficiencies

To verify the validity of diagnostic modeling result, the relationships between the total score from physical function questionnaire with physical fitness trait deficiencies were estimated by mean difference tests. Since the total score of physical function was not normally distributed across muscular strength, flexibility, aerobic endurance, balance, and fine motor skill statuses, non-parametric Wilcoxon signed-rank tests were performed to test the mean difference of

physical function scores among physical fitness trait statuses. Table 29 reports that people with any physical fitness trait deficiency were more likely to have significantly lower scores on physical function questionnaire comparing with people with sufficient physical fitness traits. All effect sizes of Cohen's d were relatively large and above 1. Among those five physical fitness traits, the total score of physical function questionnaire was changed significantly and largely from balance deficiency to sufficiency groups. Therefore, physical fitness diagnostic results were consistent with physical function measurement results.

Table 29

Comparison of Physical Function Total Score Across Diagnosed Sufficiency and Deficiency Groups on Each Physical Fitness Trait

	Muscular strength	Flexibility	Aerobic endurance	Balance	Fine motor skill
Sufficient					
Mean	361.955	362.538	364.345	359.705	362.901
SD	14.624	13.469	10.952	17.357	13.241
n	514	511	472	553	503
Deficient					
Mean	282.355	282.082	291.008	271.726	284.133
SD	54.805	53.935	54.508	54.222	54.046
n	214	217	256	175	225
Mean difference	79.6	80.46	73.34	87.98	78.77
P value	<.0001	<.0001	<.0001	<.0001	<.0001
Cohen's d effect size	2.477	2.553	2.190	2.879	2.463

Study II: Cross-Validation of Diagnostic Model

This part summarizes the cross-validation of the diagnostic model from Study I. The diagnostic modeling results were applied to compare results from performance-based fitness tests for people with Parkinson's disease in China. Table 30 reports the demographic characteristics of individuals from the China Parkinson's disease group. Overall, 45 participants answered physical function questionnaire and performed performance-based fitness tests. 60% of them were women with an average age at 63.6 (SD = 6.69). The majority were married and had earned an education degree equal or higher than high school. 60% of participants were of normal weight and only slightly over 30% of people were overweight or obese. 34.09% of people reported that they were told they had hypertension and 27.3% were diagnosed to have rheumatoid arthritis. Over 10% of the participants were stroke patients. Since all participants in this validation study were patients with Parkinson's disease, the average length of having Parkinson's disease was estimated as 70.18 (SD = 59.24) months.

Overall, 35.56% of people were muscular strength deficient and 44.44% were flexibility deficient. 26.67% of people had aerobic endurance deficiency and 31.11% of participants were deficient in balance skill. Almost half of the people (46.67%) were estimated to have fine motor skill deficiency. Over 25% of people were identified to have deficiency in only one physical fitness trait and almost half (48.89%) of people were diagnosed to be deficient in all five physical fitness traits. Regarding physical fitness profiles, 13.33% of people were deficient in only aerobic endurance with a profile "11011" and 8.89% of people (profile "01011") were sufficient only in flexibility, balance, and fine motor skill. Overall, only 6.67% of people have profile "11111" thus were sufficient in all five physical fitness traits.

Table 30

Descriptive Statistics for Individuals from China Parkinson's Disease Group

Individual characteristics	N (%) or Mean (SD)	
Age	63.60 (6.69)	
Sex	Men	18 (40.00)
	Women	27 (60.00)
Marital status	Married	42 (93.33)
	Divorced	2 (4.44)
	Widowed	1 (2.22)
Education	Junior high school	5 (11.11)
	Secondary school	7 (15.56)
	High school	10 (22.22)
	Technical degree	4 (8.89)
	College degree	18 (40.00)
	Advanced degree	1 (2.22)
Family income	< \$4,277	6 (13.33)
	\$4,277- \$6,971	14 (31.11)
	\$6,971- \$6,971	12 (26.67)
	≥ \$6,971	13 (28.89)
Body weight status	Underweight	4 (8.89)
	Normal weight	27 (60.00)
	Overweight	13 (28.89)
	Obese	1 (2.22)
Hypertension	No	29 (65.91)
	Yes	15 (34.09)
Vascular sclerosis	No	31 (79.49)
	Yes	8 (20.51)
Heart failure	No	35 (89.74)
	Yes	4 (10.26)
Stroke	No	35 (89.74)
	Yes	4 (10.26)
Rheumatoid arthritis	No	27 (72.97)
	Yes	10 (27.03)

Table 30 (cont.)

Individual characteristics	N (%) or Mean (SD)	
Asthma	No	42 (97.67)
	Yes	1 (2.33)
Diabetes	No	37 (88.10)
	Yes	5 (11.90)
Cancer	No	42 (95.45)
	Yes	2 (4.55)
Muscular strength deficiency	No	29 (64.44)
	Yes	16 (35.56)
Flexibility deficiency	No	25 (55.56)
	Yes	20 (44.44)
Aerobic endurance deficiency	No	33 (73.33)
	Yes	12 (26.67)
Balance deficiency	No	31 (68.89)
	Yes	14 (31.11)
Fine motor skill deficiency	No	24 (53.33)
	Yes	21 (46.67)
# of deficient trait	0	3 (6.67)
	1	12 (26.67)
	2	5 (11.11)
	3	2 (4.44)
	4	1 (2.22)
	5	22 (48.89)
Physical fitness profiles	00000	22 (48.89)
	11011	6 (13.33)
	11101	6 (13.33)
	01011	4 (8.89)
	00110	1 (2.22)
	01101	1 (2.22)
	11111	3 (6.67)
	Others	2 (4.44)
Parkinson's disease		
months living with		70.18 (59.24)
30-second chair stand up (count)		12.57 (4.17)
Arm curl-up (count)		16.07 (2.53)
2-min step-up (count)		110.80 (37.56)

Table 30 (cont.)

Individual characteristics	N (%) or Mean (SD)
Chair sit-reach (cm)	-8.20 (10.38)
Back stretch (cm)	-4.78 (8.41)
8-foot up and go (seconds)	9.08 (1.88)
6-min walking (meter)	469.17 (72.09)
Soda pop (seconds)	8.83 (2.42)
Cup stacking (seconds)	7.80 (2.69)

In this study, two tests such as 30-second chair stand up test and arm curl-up test were used to validate muscular strength. Back-stretch test and chair sit-reach test were used to validate flexibility. 2-min step-up test and 6-min walking test were applied to verify aerobic endurance. 8-foot up and go test was used to determine balance. To test fine motor skill, since most of the items in the PROMIS physical function questionnaire were related to hand-eye coordination, this study utilized two performance-based tests such as soda pop test and cup stacking test to testify the accuracy of diagnostic modeling results in the fine motor skill.

In order to cross-validate the diagnostic modeling results through performance-based fitness tests, three statistical analyses were conducted. First, t-tests were performed to estimate differences of continuous performance-based fitness variables among diagnosed physical fitness trait statuses. Table 31 reports mean differences of all fitness variables among sufficiency and deficiency groups.

People who were diagnosed to be deficient in muscular strength through the questionnaire had lower counts on chair stand up (Mean of Difference [MD] = 0.251, $p = 0.852$, Effect Size [ES] = 0.059) and curl-up (MD = 0.507, $p = 0.526$, ES = 0.199) compared to their counterparts in the sufficiency group. However, these differences were not significant based on p -values and small effect sizes from t-tests. Participants with flexibility deficiency had

significant bad performance in back-stretch test than those with sufficient flexibility (MD = 7.43, $p = 0.002$, ES = 0.975). This significant difference was not recognized in sit-reach test regardless the lower value (MD = 1.08, $p = 0.733$, ES = 0.103) on sit-reach test for people in the flexibility deficiency group compared to people in the sufficient group. People from the aerobic endurance deficiency group performed worse on both 6-min walking test (MD = 14.96, $p = 0.552$, ES = 0.206) and step-up test (MD = 6.354, $p = 0.623$, ES = 0.168) compared with people from aerobic endurance sufficiency group. However, these patterns were not statistically significant according to the large p -values and small effect sizes. Compared with those from the sufficiency group, participants who were diagnosed being deficient in balance skill needed an additional 1.068 seconds on the up and go test. Even though the p -value of this difference is larger than 0.05, the moderate effect size ($p = 0.079$, ES = 0.623) testified to the significant difference on balance skill among the deficiency and sufficiency groups. Concerning fine motor skill, people who were diagnosed as fine motor skill sufficiency needed significant less time on both stack test (MD = -1.607, $p = 0.027$, ES = 0.619) and soda pop test (MD = -1.085, $p = 0.135$, ES = 0.455) compared to people in the fine motor skill deficiency group. Point-biserial correlations were also conducted to get correlation coefficients among diagnosed physical fitness trait statuses and continuous performance-based fitness test results. A moderate correlation was found among diagnosed flexibility status with back-stretch test and a low correlation was observed among diagnosed fine motor skill status with the cup stacking test.

Next, the continuous diagnostic modeling results of each physical fitness trait were utilized to conduct bivariate correlation tests with corresponding performance-based fitness test results. The correlation coefficients of each physical fitness performance-based tests with estimated corresponding physical fitness traits sufficient probabilities based on EAP estimation

method were calculated, and similar results were found with the above t-tests. Moderate and low correlations were found among back stretch ($r = 0.444, p = 0.002$) and cup stacking tests ($r = -0.311, p = 0.037$) with estimated probabilities of mastering flexibility skill and fine motor skill, respectively.

Since some people in the physical fitness deficiency group were not observed to have noticeably worse performance on some of the performance-based tests such as chair stand up test, curl-up test, sit-reach test, 6-min walking test, and step-up test, these test variables were recoded into dichotomous variables based on existing senior fitness levels criteria. By comparing with fitness status from senior fitness levels criteria, the validation of diagnosed physical fitness trait statuses were evaluated again.

Table 31

t-test Results for Each Performance-based Fitness Test Across Diagnosed Physical Fitness Trait Statuses

Diagnosed fitness status	Muscular strength		Flexibility		Aerobic endurance		Balance	Fine motor skill	
	Chair stand up (count)	Curl-up (count)	Back-stretch (cm)	Sit-reach (cm)	6-min walk (m)	Step-up (count)	Up and go (second)	Soda pop (second)	Cup stacking (second)
Sufficient ^a									
Mean	12.733	16.400	-0.650	-7.600	479.750	115.417	8.346	8.253	6.940
SD	2.251	2.384	5.788	9.735	61.378	38.061	1.607	1.992	1.824
n	15	15	20	20	12	12	14	21	21
Deficient ^b									
Mean	12.483	15.893	-8.080	-8.680	464.793	109.063	9.415	9.338	8.548
SD	4.911	2.629	8.803	11.037	76.652	37.829	1.93	2.681	3.114
n	29	29	25	25	29	32	30	24	24
Mean Difference	0.251	0.507	7.430	1.080	14.957	6.354	-1.068	-1.085	-1.607
p value	0.852	0.526	0.002	0.733	0.552	0.623	0.079	0.135	0.027
Cohen's <i>d</i> Effect Size	0.059	0.199	0.975	0.103	0.206	0.168	0.623	0.455	0.619
Correlation coefficient ^c	0.0288	0.097	0.444*	0.052	0.096	0.076	-0.267	-0.226	-0.301*

Notes: a: diagnosed sufficient status for each corresponding fitness trait (e.g., 12.733 is the chair stand up test mean value of people who diagnosed to be sufficient in muscular strength); b: diagnosed deficient status for each corresponding fitness trait; c: correlations between diagnosed fitness status with corresponding performance-based fitness tests results.

According to the existing criteria of senior fitness including muscular strength, flexibility, aerobic endurance, and balance, continuous performance-based fitness test results were transformed into two levels considering their age and sex: normal (values in or above that normal range) and below average (values below that normal range). By building a confusion matrix, diagnosed physical fitness trait statuses were validated with the categorical performance-based fitness test results. The accuracy, sensitivity, specificity, and precision were calculated based on the confusion matrix (Table 32). Table 32 reports that diagnostic model results have relatively lower specificity than sensitivity on all performance-based fitness tests. The back-stretch test was found to have 62.5% specificity with diagnosed flexibility. Regarding sensitivity, diagnosed deficiency in muscular strength correctly identified 70.58% of all cases with low muscular strength in chair stand up test and 55.55% of all cases with low muscular strength in curl-up test. Concerning as flexibility, diagnosed flexibility deficiency correctly identified 65.51% of all cases with low flexibility in back-stretch test which was higher than 55.17% of all cases with low flexibility in the sit-reach test. Diagnosed deficiency of aerobic endurance correctly identified 77.77% of all cases with low aerobic endurance in the 6-min walking test and 80% of all cases with low aerobic endurance in the step-up test. In regards to balance skill, diagnosed deficiency in balance successfully identified 68.2% of all cases with low balance skill in the up and go test.

Table 32

Validation Results Based on Criterion for Senior Fitness Levels Evaluation

Diagnosed fitness status	Muscular strength		Flexibility		Aerobic endurance		Balance
	Chair stand up	Curl- up	Back- stretch	Sit- reach	6-min walk	Step-up	Up and go
Proportion of agreement (Accuracy)	0.511	0.377	0.644	0.511	0.711	0.333	0.667
Sensitivity	0.706	0.556	0.655	0.552	0.778	0.800	0.682
Specificity	0.393	0.333	0.625	0.438	0.444	0.275	0.000
Precision	0.414	0.172	0.760	0.640	0.848	0.121	0.968

CHAPTER 5: DISCUSSION

This chapter provides the dissertation study discussion. First, a brief review of the major findings on physical fitness deficiency diagnoses is provided, with a focus on the specific fitness deficiency related to aging, body weight status, and chronic diseases. Profiles of fitness deficiency by disease are described as well. The role of the diagnostic model and how it was validated are then covered. Finally, the significance and application of this study are outlined, which includes the implications of the physical function decline diagnosis application, the limitations, and future directions of this study.

Major Findings of Diagnosed Physical Fitness Trait Deficiencies

Using the physical function questionnaire from the PROMIS study, this study identified a diagnostic model that can be used for physical fitness trait deficiency diagnoses. This study estimated the prevalences of deficiency of several physical fitness traits, including muscular strength, flexibility, aerobic endurance, balance, and fine motor skill based on data from the PROMIS study. The prevalence of each physical fitness trait deficiency varied substantially across demographic characteristics. Despite these variations, the prevalences of several physical fitness trait deficiencies gradually increased with aging, even after controlling for other demographic variables including sex, race, education level completed, marital status, family income, body weight status, and chronic diseases. The odds of having all five physical fitness trait deficiencies were significantly higher in obese individuals than in normal weight individuals. This study also evidenced that there are significant relationships between chronic diseases and physical fitness trait deficiencies even after controlling for relevant confounding factors. At the same time, people with different demographic characteristics and chronic

conditions were identified different percentages of physical fitness profiles and percentages of the number of physical fitness trait deficiencies. The validation of the selected diagnostic model was also examined based on several statistic indexes.

The findings were consistent with hypotheses of this study that the DINA model can be used in kinesiology for physical fitness trait deficiency diagnosis, and the odds of all five physical fitness trait deficiencies were relatively higher in individuals that were older, obese, and had chronic diseases compared to their young, normal weight, and without chronic diseases counterparts.

Physical Fitness Deficiency in Aging

It was found that there were trends that physical fitness trait deficiencies increased as the people aged. While it is known generally that people's physical fitness decline as they age, this study derived this relationship from the physical function to aging and added to a growing literature suggesting clear patterns of physical fitness changes with age. It indicates that older individuals have higher odds of muscular strength deficiency, flexibility deficiency, aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency for both men and women when compared to younger individuals. These findings coincide with several existing studies. For example, studies found that due to the age-related reorganization of muscular subsystem resulting in dynapenia, which refers to the loss of muscle strength with aging and leads to severe physical function limitation (Clark & Manini, 2012; Manini & Clark, 2011), muscular strength was found to have declined with aging. Similarly, flexibility deficiency was found to be one of the earliest significant changes occurring in elderly adults (Chesworth & Vandervoort, 1989). When people get older, they typically become more sedentary and physically inactive. It has been demonstrated that this unhealthy lifestyle has led to an age-

related reduction in aerobic endurance as well (Raven & Mitchell, 1980). Moreover, Pollock et al. (2015) found that in people aged 55 to 79 without a history of chronic disease, their aerobic capacity worsened significantly with age. This finding is consistent with the present study that people 60 years or older have a higher prevalence and odds of aerobic endurance deficiency compared with younger people.

In addition to muscular strength, flexibility, and aerobic endurance, this study found a significant balance decline with aging. This finding is consistent with many studies on balance carried out among older adults. For example, a study found that age-related balance deficiency might due to age-related changes in sensory receptors, central nervous system structures, and skeletal muscle properties (Degani, Leonard, & Danna-dos-Santos, 2017). This age-related balance deficit was demonstrated to be linked with different rates of sarcopenia across different muscle groups (Shaffer & Harrison, 2007; Viitasalo, Era, Leskinen, & Heikkinen, 1985). In other words, it is common to have both balance deficiency and muscular strength deficiency.

In addition to the above physical fitness traits, fine motor skill deficiency was observed to be impacted by aging as well. People age 70+ have a higher prevalence and odds of fine motor skill deficiency. It can be explained by the fact that, older adults experienced brain reorganization leading to dedifferentiation of cognitive and motor area, and links between brain areas become less flexible (Forstmann et al., 2011; Heuninckx, Wenderoth, Debaere, Peeters, & Swinnen, 2005; Kennedy & Raz, 2009). Subsequently, adults with aging were encountering difficulties in hand-eye coordination and were found to experience both fine motor skills and cognitive decline (Bennett, Wilson, Boyle, Buchman, & Schneider, 2012; Hoogendam et al., 2014).

Regarding different age and sex groups, this study found that the 70-79 age range is the most dangerous period compared with other age groups among men since in this group the

prevalences of deficiency in physical fitness traits increased dramatically from the previous age groups. For women, the 60-69 age group is the period in which prevalences of deficiency in physical fitness traits increased dramatically. People 80 years and older had the highest odds on muscular strength deficiency, flexibility deficiency, aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency compared with 18-29 young age groups for both men and women.

By comparing all five physical fitness traits' patterns with age, aerobic endurance was found as the first physical fitness trait to be deficient with aging. It is obvious that aerobic endurance would decline when people are becoming more physically inactive. A longitudinal study has demonstrated that the rate of age-related reduction in aerobic capacity of the sedentary individual was 10% per decade and about 5% in highly active individuals (Posner et al., 1995). This declining trend is accelerated to more than 20% per decade after the age of 70 (Fleg, 2012; Fleg et al., 2005). Therefore, aging individuals acquire aerobic endurance deficiency initially during sedentary behaviors in their early life and experience an even greater dramatic decline in aerobic endurance after the age of 70.

In summary, older people have higher odds of muscular strength deficiency, flexibility deficiency, aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency. To succeed in healthy aging and have the possibility of an independent and high-quality life, older adults' physical capabilities such as muscular strength, flexibility, aerobic endurance, balance, and fine motor skill need to be maintained (Lin, Hsieh, Cheng, Tseng, & Su, 2016).

Physical Fitness Deficiency Across Body Weight Status

For body weight status, this study found that the odds of muscular strength deficiency, flexibility deficiency, aerobic endurance deficiency, balance deficiency, and fine motor skill

deficiency increased noticeably from normal weight group to obese group. It has been evidenced that age-related muscular strength decline and body composition changes occurred commonly together over age (Janssen, Heymsfield, & Ross, 2002). Muscular strength is demonstrated to be inversely associated with high body fat (Jackson et al., 2010). What is more, obesity could cause and worsen cardiovascular and musculoskeletal changes (Benetti, Bacha, Garrido Junior, & Greve, 2016). Therefore, it is consistent with the finding of this study that obese individuals have higher odds of muscular strength deficiency compared with normal weight individuals.

In addition to findings concerning muscular strength, flexibility was also gradually impaired in obese people due to sedentary lifestyle and/or aging, which worsens the performance of daily life activities of obese people and limits their range of motion (Júnior, 2004). Similar findings on severe flexibility deficiency in the obese group were found in this study.

Similarly, obese individuals were found to have less ability to do exhausting work compared to non-obese group, and body fat is strongly correlated with aerobic endurance (Patkar & Joshi, 2011). This finding is also consonant with the result of this study on the higher odds of aerobic endurance deficiency among obese individuals and the higher prevalence of aerobic endurance deficiency compared with other physical fitness traits. This can be explained by the difficulty to maintain postural balance and body stability in the obese individuals during walking or other position changing activities (Nieman, Ikeda, & Barbanti, 1999). This study identified the high risk of fine motor skill deficiency among the obese group. It has been verified by another study that since obese individuals have a bigger difficulty in synchronizing their movement with a visual stimulus, the fine motor coordination would be impacted (Gaul, Mat, O'Shea, & Issartel, 2016).

Overall, the diagnostic results of this study confirmed physical fitness trait deficiencies

among obese individuals. Therefore, it is warranted to design physical activity programs for obese individuals considering their physical fitness trait deficiencies. By combining personalized physical fitness levels, an individualized physical activity program could benefit people with obesity concerning their fitness and likely also address weight control.

Physical Fitness Deficiency Across Chronic Diseases

The result of this study highlights that people with different chronic diseases may have different patterns of physical fitness trait deficiencies. Therefore, findings on these patterns could partially confirm the diagnostic model's efficiency in this study. In the present study, several chronic diseases were found associated with some physical fitness trait deficiencies. For example, compared with people without diabetes, diabetic people have higher odds of having or aging into balance deficiency. This result is consistent with literatures about physical fitness levels of diabetic adults. Diabetics are commonly at high risk of the complication peripheral neuropathy which results in damage to the nerves and leads to severe sensory, motion, and mobility-related dysfunction (Allet et al., 2009; Dyck et al., 1993). In this process, diabetics with peripheral neuropathy have a higher probability of balance impairments compared to healthy people (Goldberg, Russell, & Alexander, 2008).

Another finding of this study is that people with rheumatoid arthritis were found to have higher odds on muscular strength deficiency, flexibility deficiency, aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency compared with people without rheumatoid arthritis. Muscular strength was identified to have the highest odds ratio compared with the odds ratios of other four physical fitness traits. In one previous study, people with rheumatoid arthritis already have been demonstrated to have substantial reductions in muscle density and muscle strength (Baker et al., 2014). Specifically, there was 25-70% muscular strength decline observed

among patients with rheumatoid arthritis compared with age-matched healthy controls (Stenström & Minor, 2003). Other studies also confirmed the flexibility deficiency among patients with rheumatoid arthritis. For example, one study found that muscle weakness and restricted range of motion of the joints were very typical among people with rheumatoid arthritis (Turesson & Matteson, 2007). Patients with rheumatoid arthritis suffered pains from inflammatory and destructive changes of the joints which results in limited flexibility and muscular atrophy (Herbison, Ditunno, & Jaweed, 1987). Rheumatoid arthritis patients also exhibit relatively low levels of aerobic endurance and capacity (Ekdahl & Broman, 1992). Additionally, a study found that rheumatoid arthritis disease decreased some motor performance functions especially for hand-related coordination movements (Kauranen, Vuotikka, & Hakala, 2000). Overall, rheumatoid arthritis is a disease that impacts people's physical fitness. The findings of this study comprehensively confirmed these patterns.

The odds of muscular strength deficiency among people with cancer was much higher than people without cancer. This is consistent with a finding that pancreatic cancer patients had noticeably impaired physical fitness on muscular strength (Clauss et al., 2017). Even though the present study did not show cancer types, cancer-related muscle dysfunction not only exists among pancreatic cancer patients but also other kinds of cancer at different stages (Christensen et al., 2014). The possible factors that lead to this muscular strength deficiency among cancer patients includes physical inactivity, tumor-derived factors, cancer treatments, and medications (Lakoski, Eves, Douglas, & Jones, 2012).

In this study, people with hypertension have higher odds of balance deficiency and aerobic endurance deficiency when compared to people without hypertension. Increased blood pressure was evidenced to impact balance, gait, fall risks, and a decrease in aerobic capacity

(Hausdorff, Herman, Baltadjieva, Gurevich, & Giladi, 2003; Mazic et al., 2015). In addition, people with lung disease were found significantly higher odds of deficiencies in muscular strength, flexibility, aerobic endurance, balance, and fine motor skill compared with people without lung disease. Among those associations, muscular strength deficiency has the highest odds compared with the other four physical fitness traits. Overall, fitness capacity, especially for muscular strength, flexibility, aerobic endurance, and balance were markedly reduced in people with lung disease (Pinto-Plata et al., 2007; Shephard & Cox, 1980). People with lung disease, this study confirmed, are at high risk of having physical fitness trait deficiencies.

When some similar chronic diseases are combined as a group, the results of physical fitness deficiency were also confirmed by the above literature. For example, people with musculoskeletal disease have highest odds ratios of deficiencies in muscular strength, flexibility, aerobic endurance, balance, and fine motor skill compared with people without musculoskeletal, cardiometabolic, and respiratory diseases. Furthermore, people with only musculoskeletal were found to have significantly higher odds of muscular strength deficiency, flexibility deficiency, aerobic endurance deficiency, balance deficiency, and fine motor skill deficiency compared with people with only cardiometabolic or only respiratory diseases. Specifically, muscular strength deficiency has the highest odds ratio compared with the other four physical fitness traits. Therefore, it is apparent that people with the musculoskeletal disease (such as people with osteoarthritis) have a higher risk of muscular strength decline which could impact other fitness components.

Physical Fitness Profiles and Chronic Diseases

This study found that compared to other physical fitness profiles besides 00000 and 11111, the 00010 profile has a higher percentage among people 60 years and older. It indicates

that even when people age, balance persists when the other four physical fitness traits are deficient. This result coincided with the trends of physical fitness trait deficiencies with aging illustrated in Figure 7. Additionally, the results of this study revealed that people with different chronic diseases may have varied physical fitness profiles. For example, stroke and rheumatoid arthritis patients were found to have high percentages (11.11% and 10.95%, respectively) of 00010 fitness profile, which illustrates that these two diseases had similar fitness deficiencies in muscular strength, flexibility, aerobic endurance, and fine motor skill.

Diagnostic Model Validation

Being able to explore the underlying fitness traits from physical functional measures in this study was largely due to the identified diagnostic model. This study used the PROMIS dataset to validate the diagnostic modeling process and furtherly used a dataset from a Chinese Parkinson's disease group to cross-validate the diagnostic model. Based on mean comparison results on the total score of PROMIS physical function items, noticeable differences across deficiency group and sufficiency group of all five physical fitness traits were found. Moreover, all effect sizes of Cohen's d were relatively large and above 2. Since a higher total score of physical function means a higher level of physical function, it was obvious that individuals who were diagnosed to be deficient in any of the physical fitness traits had lower scores on the physical function matrix. Therefore, the selected diagnostic model in this study to diagnose individuals' physical fitness trait statuses can discriminate individuals' responses to physical function questionnaire very well. In other words, individuals' level of physical function decline can be discriminated by the results obtained from the DINA model.

Additionally, this study highlights the cross-validation results by comparing the diagnosed fitness statuses to performance-based physical fitness tests result. t-tests were

performed to estimate mean differences in nine continuous performance-based fitness variables among diagnosed physical fitness trait statuses. The finding shows that individuals who were diagnosed to be deficient in flexibility have significantly lower scores on a flexibility test (backstretch test). The t-test results also confirmed the validity of DINA model on diagnoses of balance deficiency and fine motor skill deficiency. Even though people in the sufficient group have better performance on both muscular strength and aerobic endurance tests, no significant differences of muscular strength tests and aerobic endurance tests were identified across diagnosed muscular strength sufficiency/deficiency groups and aerobic endurance sufficiency/deficiency groups, respectively. A few factors might contribute to this. For example, the sample size is too small and there was an unbalanced dataset across sufficiency and deficiency groups. Since only 45 participants completed both the physical function questionnaire and performance-based physical fitness tests, the real significant difference of muscular strength and aerobic endurance tests may not have been accurately obtained. Therefore, it is necessary to classify individuals into two groups based on their performance-based fitness tests and compare these results with the diagnosed physical fitness trait statuses.

Based on existing age- and sex- physical fitness test criterion, individuals were classified into normal and below average groups on specific fitness tests. The finding of this study shows that the diagnosed muscular strength deficiency correctly identified over 70% of people with below average of lower-body muscular strength and over 55% of people with below average of upper-body muscular strength. What is more, diagnosed aerobic endurance deficiency correctly identified over 77% of people with below average of aerobic endurance. Overall, people with deficient lower-body muscular strength can be better diagnosed compared with people with deficient upper-body muscular strength. Regarding upper-body flexibility and lower-body

flexibility capacity, people with deficient upper-body flexibility were better diagnosed than people with deficient lower-body flexibility. This might be explained partially by the simple fitness test (curl-up and sit-reach) used in testing muscular strength and flexibility which may not discriminate people with different levels of upper-body muscular strength and lower-body flexibility, respectively. Furthermore, another possible reason might be the physical function questionnaire used in this study having more items on measuring the lower-body muscular strength and upper-body flexibility. These unbalanced item numbers in the diagnostic modeling process might dilute the measurement accuracy of lower-body muscular strength and upper-body flexibility. In conclusion, the diagnostic model selected by this study can be used to diagnose people with deficient lower-body muscular strength, deficient upper-body flexibility, deficient aerobic endurance, deficient balance, and deficient fine motor skill. The diagnostic accuracy on upper-body muscular strength and lower-body flexibility should be increased in future research.

Application and Significance

According to the above reported results, the ultimate application of this study is to provide individualized diagnosed information which can be used in physical activity intervention design for people with functional decline and to protect them from becoming disability or slowing the speed of decline in physical function.

When people get older, the number of disabled people increases. Disability is not only a threat to people's health and quality of life but also an issue for society as a whole. Elderly disabled people are hospitalized more often and require more long-term care (Allen & Ciambrone, 2003). Several conceptual models have been determined useful for modeling the progression of physical function deficiency to disability. According to a well-known description of disability (Nagi, 1991), the theoretical pathway from disease to disability is from pathology to

physical impairment, to functional limitation, and finally resulting in disability. From this theoretical pathway, it is obvious that physical function status is a key part of the pathway from disease to disability.

Physical function decline may be prevented or reduced by daily exercise and physical activities. For example, Yorston, Kolt, & Rosenkranz (2012) mentioned that higher levels of daily physical activity were related to better physical function in adults and physical activity was found to be associated with improved physical function after a 4-month community intervention (Fitzpatrick et al., 2008). Therefore, it is necessary to design appropriate physical activity interventions for people with functional decline accurately and efficiently (Pike, 2011). However, current exercise prescriptions are commonly provided by physicians, which requires people to actually see a doctor. This could be an issue for people who already have physical function decline because of the physical difficulty in going to see a doctor regularly to have physical function test and then obtaining exercise prescriptions. In addition, the traditional individualized exercise intervention design could be a major economic burden for people without health insurance or health insurance that does not cover preventative medicine or such treatment. Also, people who have physical function problems require a timely assessment of their physical function capacity and need efficient physical activity interventions to prevent them from being disabled. This assessment should also be consistent and tracked so that people with functional decline can be encouraged by the tracking status of their fitness especially if it reverses or at the very least maintains present level.

Ultimately, to address all the above problems and make exercise prescription easily available, this study provides a possible approach using the diagnostic model analysis methods to diagnose individual's physical fitness problems from a physical function questionnaire.

This study can be used to assess people's physical function limitations on daily tasks by occupational therapists. At the same time, it could guide physical therapists to diagnose the physical source of functional decline and provide possible treatments based on the diagnosed underlying fitness deficiencies.

The application of this study could help people with functional decline by providing individualized exercise and activity suggestions accurately to help offset possibility of coming disabled. To design an individualized physical activity intervention, the major physical fitness deficiency can be identified firstly by using this study's method. After the diagnoses, the personalized physical activity intervention design must also consider age, sex, and any chronic conditions. By implementing this study results in an online platform, this study can be employed to provide an opportunity for people with functional decline to diagnose their physical fitness status and encouraging them to take actions to prevent more physical function capacity loss. At the same time, physical function status tracking can also be achieved by using this online platform regularly. In summary, this study will be beneficial for people with functional decline and may help them from becoming disabled.

Overall, the application of the diagnostic model in fitness assessment could contribute a new kinesiology knowledge system theory, which not only can be used in the exercise and physical activity area but also in other health-related assessments areas. Simultaneously, this study contributes to exercise intervention and program design by paying attention to stressing the importance of physical fitness diagnoses.

Strength

To my knowledge, the present work is the first study to diagnose physical fitness trait deficiencies based on physical function questionnaire responses by using diagnostic modeling

techniques. This study is unique due to three reasons: it is the first study to find the linking relationship between physical function questionnaire items and physical fitness traits; it is the first study to use the diagnostic model to explore the status of physical fitness traits based solely on a physical function questionnaire; and it is the first study to make the designing of an exercise intervention possible based on physical function questionnaire assessment results.

This study explored physical fitness traits which pertained to the traditional physical function questionnaire items. Commonly, researchers paid the most attention to the overall physical function score, and they used this score to classify groups into different physical functional levels (Hung, Clegg, Greene, & Saltzman, 2011; Idler, Russell, & Davis, 2000). Then a classified group or total physical function score was used to do further statistical analyses. According to the literature review, none of the existing studies had reasonably disclosed the linking relationships between underlying physical fitness traits and physical function assessment items.

Therefore, based on the PROMIS physical function questionnaire, this study discovered the underlying physical fitness traits' information for each physical function item. It will advocate for more researchers to not only focus on the physical function as a whole but pay more attention to physical parameters so that this information can be diagnosed to benefit more people with functional decline. In addition, the linking information between the physical fitness components and physical function items could help researchers to rethink the design/selection/offering of physical function items. Currently, many items from the physical function questionnaire are very simple. According to the result from this study, researchers could design more complicated and more real-life items to measure people's physical function in daily life.

In addition, this study is the first to apply the diagnostic model in kinesiology. The diagnostic model is a popular psychometric theory in the field of educational measurement (Henson, Templin, & Willse, 2009). However, there is no literature in kinesiology using this modern method until now. Most researchers in kinesiology use traditional measurement methods, such as classical test theory and item response theory. Both of those methods also could provide an estimation of people's physical function level. However, physical function level estimation can only tell us which group did well and who is the best. These two traditional methods cannot explain the specific physical reasons why one group of people have a lower level of physical function than another group of people. For example, a traditional physical function score has no information on what is the participant's strength level and is his/her flexibility good enough to do daily life activities that require flexibility?

Therefore, this study used the diagnostic model to explore people's underlying physical fitness aspects from their physical function measurements. As a result, rich patterns or profile information embedded in the functional measures can be obtained. Thus, by using the diagnostic modeling method, this study answered the question why some people with declined physical function cannot do some daily life activities.

Finally, since physical function decline is a symptom for some diseases (Marchione, 2016; Riazi et al., 2003), physicians have simply regarded physical function assessment as means for disability levels estimation and also a possible tool for disease diagnoses. It is hard for them to design physical activity intervention purely using physical function questionnaire assessments. The reason might be a missing key-physical fitness traits-which cannot be found by traditional physical function assessment methods and scores.

By linking the relationship between physical function items and physical fitness traits and apply the diagnostic model in the physical function questionnaire, this study provided the missing key fitness levels, so that this study makes an exercise prescription based on physical function questionnaire assessment possible. Therefore, it is the first study to make the designing of an exercise intervention possible based on physical function questionnaire assessment.

Limitations

A few limitations pertaining to this study should be noted. First, the sample size of the Chinese Parkinson's disease group might compromise the diagnostic precision of physical fitness trait statuses. Since some participants' responses to physical function questionnaire or test results from performance-based physical fitness tests were missing, the number of participants who had both complete physical function questionnaire and performance-based physical fitness tests data was relatively small. Therefore, significant differences of adults' several performance-based physical fitness test scores such as sit-reach and the 2-min step-up among diagnosed physical fitness trait statuses could not be observed. Moreover, Chinese adults were used in the process of diagnostic model validation in this study, and there might have been some health disparities among U.S. adults and Chinese adults. Since the relationship between physical fitness and physical function was testified in the introduction part based on several studies from different countries, these health disparities might be ignored.

Second, this study tested three diagnostic models from three different model families, such as DINO model from the compensatory model family, DINA model from the non-compensatory model family, and GDINA model from the general model family. Many diagnostic models were developed by researchers in the educational measurement areas. Therefore, most data which were used in the diagnostic modeling process are categorical or dichotomous data.

However, in this study, participants' original responses to physical function items are ordinal, not dichotomous. To ensure the accuracy of the modeling process, all participants' responses had to be recoded as dichotomous, which might comprise the different levels of response for people with functional decline. This recoding also has some impact on the dose recommendation of physical activity based on diagnosed physical fitness trait deficiencies. Even though few studies already have developed new diagnostic models for ordinal response data (Ma & de la Torre, 2016), the model design which can be applied on educational ordinal response data is not appropriate for physical function data. Therefore, it might be more practical to develop some new diagnostic models which can be applied to ordinal physical health data in the future. What is more, for dichotomous response data, there are other famous diagnostic models in the education measurement area, but this study cannot apply them all and compare them with the DINA model due to the limited sample size to estimate too many parameters in those models.

Third, this study is also primarily limited by its sample size of participants with chronic diseases in PROMIS Wave I study. For example, only few people with spinal cord injury ($n = 18$) or stroke ($n = 26$) were included in this study, which cannot be considered representative of these diseases groups to whom the associations with fitness trait deficiencies can be generalized. A larger sample size would offer a clearer conclusion about the associations between chronic diseases and physical fitness trait deficiencies. Further research with larger samples with different types of disease, such as cardiometabolic, musculoskeletal or respiratory diseases, would have shown their association results with physical fitness trait deficiencies.

Fourth, the diagnostic results on physical fitness traits are not sufficient for an exercise intervention dose recommendation. In the present study, based on the estimated continuous probability of physical fitness trait deficiency, it can be used to determine how severe that

person's deficiency in that trait is. If the probability is very low and close to 0, a higher dose of exercise intervention may be needed since that person has a significant loss of that physical trait. If the probability is very close to 0.5 but lower than 0.5 (the traditional cutoff score for dichotomous status), a lower dose of exercise intervention may be needed. Even though the estimated continuous probability of physical fitness trait deficiency could provide guidance on an exercise intervention prescription dose, the specific dose of physical activity intervention cannot be read simply from the probability of physical fitness trait deficiency. Therefore, for the dose suggestions, further research and experiments are required, so that accurate dose of exercise intervention can be determined. This would be a continuation of this study, which is based on the diagnostic results to design exercise intervention not only on types of physical activity but also the dose of physical activity. Some experiments can be designed to estimate the accurate amount of exercise intervention. For example, participants can be divided into several exercise intervention dose groups. Among each group, participants' physical fitness trait deficiencies can be measured using the diagnostic model before and after physical activity intervention. By comparing participants' physical fitness trait statuses among all exercise intervention groups, the linking between fitness deficiencies and a specific dose of exercise interventions can be developed.

Future Directions

The present study is the first study to investigate the diagnostic modeling on physical function questionnaire. Even though this study demonstrated the significance of the diagnostic modeling on catching physical function decline, these results are just the beginning of the diagnostic modeling in kinesiology concerning physical activity. Several future directions should be considered to apply the results of this study into real-life.

This study evidenced the effectiveness of diagnosed physical fitness trait deficiencies based on physical function questionnaire from the PROMIS study. The number of physical function items is too large, which might cost too much time for participants making it unlikely for them to answer all physical function items used in this study. Therefore, it is necessary to conduct an item reduction analysis on the physical function questionnaire. By considering the following aspects such as item contents, the Q-matrix development, and physical fitness traits, an item reduction analysis could not only reduce the number of items but also maintain a high accuracy of the diagnostic fitness results when compared with using all items mentioned in this study.

This study found the linking of physical fitness status with physical function decline. Ultimately, this study advocates for a new future direction in physical activity promotion for people with functional decline that uses diagnosed physical fitness traits to guide exercise prescription. The practice of assessing physical fitness trait statuses and profiles could personalize individual's status of physical fitness components, hence allowing for customizing of physical activity prescriptions. In general, a person's physical fitness profile makes an individualized exercise prescription possible, which could guide him/her to change his/her behavior and then effectively improve physical function. Since this study only proposed five physical fitness traits, if those five physical fitness traits can be broken down into more detail, the design of more purposeful exercise interventions would be possible. To break down fitness traits, it is necessary to get more detailed information from self-reported physical function items. So, in the future research, it will be very meaningful to redesign physical function items by adding more follow up questions when people responded they have difficulties in performing a daily life activity and differentiating the question about daily life activity according to physical

fitness traits, body positions, and even orders of movements. Overall, designing individualized exercise prescriptions based on diagnosed physical fitness trait statuses is warranted to try to prevent people with functional decline from becoming disabled.

This study's final future direction is to prevent people from possible physical function decline by the development of an online platform to diagnose individuals' physical fitness trait statuses and influence individuals' behavior change. Therefore, it is necessary to design an online platform to assess people's physical function, diagnose their physical fitness profile, and then provide personalized exercise prescription, electronically. Making these functions available online could save time to measure and benefit a large group of people who have access to the Internet. Since people who have problems in their daily life activities and physical function already have been hindered by physical issues in going somewhere for performance-based physical fitness assessments, questionnaire assessments could be used as an alternative way to measure their physical problems and a record would be maintained remotely and electronically. Therefore, for people who have physical function problems, they could take the corresponding questionnaire assessment online and then obtain their diagnosed physical fitness profiles and exercise prescriptions without physically having to go somewhere. Such online resources would allow more people to be involved in diagnosis of physical function decline. Subsequently, online techniques could benefit more people with functional decline and might help prevent them from more severe disability.

Conclusion

Based on the findings of this study, it can be concluded as follows:

1. Using physical function questionnaire from the PROMIS study, this study identified a diagnostic model that can diagnose adults' physical fitness trait statuses. The

validation results confirmed that the diagnostic model selected by this study can be used to diagnose people with deficiencies in lower-body muscular strength, upper-body flexibility, aerobic endurance, balance, and fine motor skill. The diagnostic accuracy on upper-body muscular strength and lower-body flexibility needs to be increased through future research;

2. The diagnostic model can reveal people's physical fitness trait statuses and profiles in regard to aging. The diagnostic results are consistent with real patterns of older adult's physical fitness;
3. This diagnostic model can identify obese people as having higher risks of physical fitness deficiency. This diagnostic modeling method can target fitness deficiency patterns of people with chronic diseases;
4. There is a need to reduce number of physical function questionnaire items and develop an online platform for physical fitness traits diagnosis to help people with functional decline from possible progression into disability.

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APPENDIX A: ITEMS FROM PROMIS PHYSICAL FUNCTION BANK A AND BANK

B

	Item
PFA1	Does your health now limit you in doing vigorous activities, such as running, lifting heavy objects, participating in strenuous sports?
PFA2	Does your health now limit you in exercising regularly?
PFA3	Does your health now limit you in bending, kneeling, or stooping?
PFA4	Does your health now limit you in doing heavy work around the house like scrubbing floors, or lifting or moving heavy furniture?
PFA5	Does your health now limit you in lifting or carrying groceries?
PFA6	Does your health now limit you in bathing or dressing yourself?
PFA7	How much do physical health problems now limit your usual physical activities (such as walking or climbing stairs)?
PFA8	Are you able to move a chair from one room to another?
PFA9	Are you able to bend down and pick up clothing from the floor?
PFA10	Are you able to stand for one hour?
PFA11	Are you able to do chores such as vacuuming or yard work?
PFA12	Are you able to push open a heavy door?
PFA13	Are you able to exercise for an hour?
PFA14	Are you able to carry a heavy object (over 10 pounds)?
PFA15	Are you able to stand up from an armless straight chair?
PFA16	Are you able to dress yourself, including tying shoelaces and doing buttons?
PFA17	Are you able to reach into a high cupboard?
PFA18	Are you able to use a hammer to pound a nail?
PFA19	Are you able to run or jog for two miles?
PFA20	Are you able to cut your food using eating utensils?
PFA21	Are you able to go up and down stairs at a normal pace?
PFA22	Are you able to open previously opened jars?
PFA23	Are you able to go for a walk of at least 15 minutes?
PFA24	Are you able to climb several flights of stairs?
PFA25	Are you able to do yard work like raking leaves, weeding, or pushing a lawn mower?
PFA26	Are you able to do two hours of physical labor?
PFA27	Are you able to run on uneven ground?
PFA28	Are you able to open a can with a hand can opener?
PFA29	Are you able to pull heavy objects (10 pounds) towards yourself?
PFA30	Are you able to step up and down curbs?
PFA31	Are you able to get up off the floor from lying on your back without help?
PFA32	Are you able to stand with your knees straight?
PFA33	Are you able to exercise hard for half an hour?
PFA34	Are you able to wash your back?

APPENDIX A (*cont.*)

	Item
PFA35	Are you able to open and close a zipper?
PFA36	Are you able to put on and take off a coat or jacket?
PFA37	Are you able to stand for short periods of time?
PFA38	Are you able to dry your back with a towel?
PFA39	Are you able to run at a fast pace for two miles?
PFA40	Are you able to turn a key in a lock?
PFA41	Are you able to squat and get up?
PFA42	Are you able to carry a laundry basket up a flight of stairs?
PFA43	Are you able to write with a pen or pencil?
PFA44	Are you able to put on a shirt or blouse?
PFA45	Are you able to get out of bed into a chair?
PFA46	Are you able to cut your toe nails?
PFA47	Are you able to pull on trousers?
PFA48	Are you able to peel fruit?
PFA49	Are you able to bend or twist your back?
PFA50	Are you able to brush your teeth?
PFA51	Are you able to sit on the edge of a bed?
PFA52	Are you able to tie your shoelaces?
PFA53	Are you able to run errands and shop?
PFA54	Are you able to button your shirt?
PFA55	Are you able to wash and dry your body?
PFA56	Are you able to get in and out of a car?
PFB1	Does your health now limit you in doing moderate work around the house like vacuuming, sweeping floors or carrying in groceries?
PFB2	Does your health now limit you in driving a car or using public transportation?
PFB3	Does your health now limit you in putting a trash bag outside?
PFB4	Does your health now limit you in dancing for half an hour?
PFB5	Does your health now limit you in hiking a couple of miles on uneven surfaces, including hills?
PFB6	Does your health now limit you in eating a meal within a normal time?
PFB7	Does your health now limit you in doing strenuous activities such as backpacking, skiing, playing tennis, bicycling or jogging?
PFB8	Are you able to carry two bags filled with groceries 100 yards?
PFB9	Are you able to jump up and down?
PFB10	Are you able to climb up five steps?
PFB11	Are you able to wash dishes, pots, and utensils by hand while standing at a sink?
PFB12	Are you able to make a bed, including spreading and tucking in bed sheets?
PFB13	Are you able to carry a shopping bag or briefcase?
PFB14	Are you able to take a tub bath?
PFB15	Are you able to change the bulb in a table lamp?

APPENDIX A (*cont.*)

	Item
PFB16	Are you able to press with your index finger (for example ringing a doorbell)?
PFB17	Are you able to put on and take off your socks?
PFB18	Are you able to shave your face or apply makeup?
PFB19	Are you able to squeeze a new tube of toothpaste?
PFB20	Are you able to cut a piece of paper with scissors?
PFB21	Are you able to pick up coins from a table top?
PFB22	Are you able to hold a plate full of food?
PFB23	Are you able to pour liquid from a bottle into a glass?
PFB24	Are you able to run a short distance, such as to catch a bus?
PFB25	Are you able to push open a door after turning the knob?
PFB26	Are you able to shampoo your hair?
PFB27	Are you able to tie a knot or a bow?
PFB28	Are you able to lift 10 pounds above your shoulder?
PFB29	Are you able to lift a full cup or glass to your mouth?
PFB30	Are you able to open a new milk carton?
PFB31	Are you able to open car doors?
PFB32	Are you able to stand unsupported for 10 minutes?
PFB33	Are you able to remove something from your back pocket?
PFB34	Are you able to change a light bulb overhead?
PFB35	Are you able to open and close your mouth?
PFB36	Are you able to put on a pullover sweater?
PFB37	Are you able to turn faucets on and off?
PFB38	Are you able to wash your face with a washcloth?
PFB39	Are you able to reach and get down a 5-pound object from above your head?
PFB40	Are you able to stand up on tiptoes?
PFB41	Are you able to trim your fingernails?
PFB42	Are you able to stand unsupported for 30 minutes?
PFB43	Does your health now limit you in taking care of your personal needs (dress, comb hair, toilet, eat, bathe)?
PFB44	Does your health now limit you in doing moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf?
PFB45	Does your health now limit you in taking part in any sports (swimming, bowling, and so forth)?
PFB46	Does your health now limit you in doing housework or jobs around the house?
PFB47	Does your health now limit you in doing recreational activities which require little exertion (e.g., card playing, knitting, etc.)?
PFB48	Does your health now limit you in taking a shower?
PFB49	Does your health now limit you in going for a short walk (less than 15 minutes)?
PFB50	How much difficulty do you have doing your daily physical activities, because of your health?

APPENDIX A (*cont.*)

	Item
PFB51	Does your health now limit you in participating in active sports such as swimming, tennis, or basketball?
PFB52	Does your health now limit you in pursuing your hobbies or other leisure activities?
PFB53	Does your health now limit you in making coffee or tea?
PFB54	Does your health now limit you in going OUTSIDE the home, for example to shop or visit a doctor's office?
PFB55	Does your health now limit you in traveling out of town for an overnight stay?
PFB56	Are you able to lift one pound (a full pint container) to shoulder level without bending your elbow?

**APPENDIX B: CONTINGENCY TABLE AMONG THREE RATERS FOR EACH
PHYSICAL FITNESS TRAIT**

ID	Muscular strength		Flexibility		Mobility		Aerobic endurance		Balance		Hand-eye coordination	
	0	1	0	1	0	1	0	1	0	1	0	1
PFA01	0	3	0	3	0	3	0	3	0	3	2	1
PFA02	0	3	1	2	0	3	1	2	0	3	3	0
PFA03	0	3	0	3	2	1	3	0	0	3	3	0
PFA04	0	3	1	2	0	3	1	2	0	3	2	1
PFA05	0	3	2	1	2	1	3	0	0	3	3	0
PFA06	1	2	0	3	3	0	3	0	0	3	3	0
PFA08	0	3	2	1	1	2	3	0	0	3	3	0
PFA09	3	0	0	3	3	0	3	0	1	2	2	1
PFA10	0	3	3	0	3	0	2	1	1	2	3	0
PFA11	0	3	1	2	0	3	2	1	0	3	2	1
PFA12	0	3	1	2	2	1	3	0	0	3	2	1
PFA13	0	3	2	1	2	1	0	3	0	3	3	0
PFA14	0	3	2	1	3	0	3	0	1	2	3	0
PFA15	0	3	2	1	2	1	3	0	0	3	3	0
PFA16	2	1	0	3	3	0	3	0	0	3	2	1
PFA17	1	2	0	3	3	0	3	0	1	2	2	1
PFA18	1	2	2	1	3	0	3	0	2	1	0	3
PFA19	1	2	2	1	0	3	0	3	0	3	3	0
PFA20	1	2	2	1	3	0	3	0	1	2	1	2
PFA21	0	3	1	2	0	3	2	1	0	3	3	0
PFA23	1	2	2	1	0	3	1	2	1	2	3	0
PFA27	1	2	2	1	0	3	1	2	0	3	3	0
PFA28	0	3	2	1	3	0	3	0	2	1	0	3
PFA29	0	3	3	0	3	0	3	0	1	2	3	0
PFA30	0	3	2	1	1	2	3	0	0	3	3	0
PFA31	0	3	2	1	2	1	3	0	0	3	3	0
PFA32	0	3	3	0	2	1	3	0	0	3	3	0
PFA33	1	2	2	1	3	0	1	2	2	1	3	0
PFA34	2	1	0	3	3	0	3	0	2	1	3	0
PFA35	1	2	2	1	3	0	3	0	2	1	2	1
PFA36	1	2	0	3	3	0	3	0	1	2	2	1
PFA37	1	2	3	0	3	0	3	0	0	3	3	0
PFA38	1	2	0	3	3	0	3	0	1	2	3	0
PFA39	1	2	2	1	0	3	0	3	1	2	3	0
PFA40	1	2	2	1	3	0	3	0	3	0	1	2
PFA41	0	3	2	1	2	1	3	0	0	3	3	0

APPENDIX B (cont.)

ID	Muscular strength		Flexibility		Mobility		Aerobic endurance		Balance		Hand-eye coordination	
	0	1	0	1	0	1	0	1	0	1	0	1
PFA42	0	3	2	1	0	3	3	0	0	3	3	0
PFA43	1	2	2	1	3	0	3	0	2	1	0	3
PFA44	1	2	0	3	2	1	3	0	1	2	3	0
PFA45	0	3	1	2	1	2	3	0	0	3	3	0
PFA47	1	2	0	3	3	0	3	0	0	3	3	0
PFA48	1	2	2	1	3	0	3	0	2	1	0	3
PFA49	2	1	0	3	3	0	3	0	1	2	3	0
PFA50	1	2	2	1	3	0	3	0	1	2	1	2
PFA51	0	3	3	0	2	1	3	0	0	3	3	0
PFA52	1	2	1	2	3	0	3	0	2	1	0	3
PFA53	1	2	2	1	0	3	1	2	0	3	2	1
PFA54	1	2	2	1	3	0	3	0	2	1	0	3
PFA55	1	2	0	3	3	0	3	0	0	3	3	0
PFA56	0	3	0	3	2	1	3	0	0	3	3	0
PFB01	0	3	2	1	0	3	1	2	0	3	2	1
PFB03	0	3	2	1	0	3	3	0	0	3	3	0
PFB04	1	2	2	1	0	3	0	3	0	3	3	0
PFB05	1	2	2	1	0	3	0	3	0	3	3	0
PFB07	0	3	1	2	0	3	0	3	0	3	3	0
PFB08	0	3	2	1	1	2	2	1	0	3	3	0
PFB09	0	3	2	1	2	1	3	0	1	2	3	0
PFB10	1	2	2	1	0	3	3	0	0	3	3	0
PFB11	1	2	2	1	3	0	3	0	0	3	1	2
PFB12	1	2	0	3	2	1	3	0	0	3	1	2
PFB13	0	3	3	0	3	0	3	0	0	3	3	0
PFB14	1	2	0	3	2	1	3	0	0	3	3	0
PFB15	1	2	2	1	3	0	3	0	1	2	0	3
PFB16	1	2	1	2	3	0	3	0	3	0	1	2
PFB17	1	2	0	3	3	0	3	0	2	1	2	1
PFB18	1	2	2	1	3	0	3	0	1	2	1	2
PFB19	1	2	2	1	3	0	3	0	2	1	1	2
PFB20	1	2	2	1	3	0	3	0	2	1	1	2
PFB21	2	1	2	1	3	0	3	0	1	2	0	3
PFB22	0	3	3	0	3	0	3	0	1	2	2	1
PFB23	1	2	1	2	3	0	3	0	1	2	0	3
PFB24	1	2	2	1	0	3	2	1	0	3	3	0
PFB25	0	3	2	1	3	0	3	0	1	2	2	1
PFB26	1	2	1	2	3	0	3	0	1	2	2	1
PFB27	1	2	2	1	3	0	3	0	1	2	0	3

APPENDIX B (cont.)

ID	Muscular strength		Flexibility		Mobility		Aerobic endurance		Balance		Hand-eye coordination	
	0	1	0	1	0	1	0	1	0	1	0	1
PFB28	0	3	1	2	3	0	3	0	1	2	3	0
PFB29	1	2	1	2	3	0	3	0	1	2	0	3
PFB30	0	3	2	1	3	0	3	0	1	2	1	2
PFB31	0	3	2	1	3	0	3	0	0	3	2	1
PFB32	1	2	3	0	3	0	2	1	0	3	3	0
PFB33	1	2	0	3	3	0	3	0	1	2	3	0
PFB34	1	2	0	3	3	0	3	0	1	2	0	3
PFB36	1	2	0	3	3	0	3	0	1	2	3	0
PFB37	1	2	1	2	3	0	3	0	1	2	1	2
PFB39	1	2	0	3	3	0	3	0	0	3	0	3
PFB40	0	3	2	1	3	0	3	0	0	3	3	0
PFB41	1	2	2	1	3	0	3	0	2	1	0	3
PFB42	1	2	3	0	3	0	2	1	0	3	3	0
PFB43	0	3	0	3	1	2	2	1	0	3	0	3
PFB44	0	3	1	2	0	3	0	3	0	3	1	2
PFB45	0	3	0	3	0	3	0	3	0	3	1	2
PFB48	1	2	0	3	3	0	3	0	0	3	3	0
PFB49	1	2	2	1	0	3	3	0	0	3	3	0
PFB50	0	3	0	3	0	3	0	3	0	3	1	2
PFB51	0	3	0	3	0	3	0	3	0	3	1	2
PFB54	1	2	2	1	0	3	2	1	0	3	3	0
PFB56	0	3	1	2	3	0	3	0	1	2	3	0