ORIGINAL ARTICLE

Smartphone frailty screening: Development of a quantitative early detection method for the frailty syndrome

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Abstract

Background: Frailty syndrome in older population generates formidable social cost. The early detection of "prefrail" stage is essential so that interventions could be performed to prevent deterioration. The purpose of this study was to organize appropriate physical performance tests into a computerized early frailty screening platform, called frailty assessment tools (FAT) system, to detect individuals who are in the prefrail stage.

Methods: Four switches, one distance meter, and one power measure were adopted to build the FAT system that could perform six physical performance tests including single leg standing (SLS), repeated chair rise, timed up and go, self-selected walking speed, functional reach, and grip power. Participants over 65 years old were recruited and classified into three groups according to Fried criteria. The differences in variables between prefrail and robust groups were compared by the χ^2 test, independent samples *t* test, and Mann-Whitney *U* test, for nominal variables, normal, and non-normal distributive continuous variables, respectively. The statistically significant level was set at 0.05 ($\alpha = 0.05$).

Results: Only SLS did not reach significance to distinguish prefrail from robust. Among 35 participants (73.23 ± 5.70 years old), the FAT score predicted that 90.73 ± 19.95% of pre-frail subjects and 15.01 ± 25.25% of robust subjects were in the prefrail stage.

Conclusion: The FAT system, which provides results immediately, is an advantageous alternative to traditional manual measurements. The use of the FAT score for predicting the prefrail stage will help to provide early intervention to prevent individuals from progressing into frailty. The FAT system provides a more convenient and comprehensive frailty screening. Using this computerized automatic screening platform, it may be possible to expand the scope of frailty prevention.

Keywords: Aging; Elderly, frail; Frailty; Physical functional performance

1. INTRODUCTION

Currently, frailty syndrome is a novel but emerging concept in geriatrics. Unlike old age, comorbidity, and disability,[1] frailty is generally considered to be part of a transition period preceding the occurrence of dysfunction in older adults.[2,3] It is not only the precursor of functional degradation in elderly populations but also the onset of multiple vicious cycles of aging-related syndromes.[4] Frailty represents many aggregated phenomena such as weight loss, sarcopenia, fatigue, appetite loss, abnormal gait and balance, as well as bone loss, which result from common clinical symptoms.[4] In addition, some scholars have proposed to assess the occurrence and severity of the frailty syndrome to predict aging-related health deterioration[5] and the probability of adverse conditions such as falls, fractures, and death.[6] Therefore, compared with the simple concept of aging, frailty is clinically more important for older adult population.

In general, the factors contributing to frailty can be classified into two groups (i.e., biomedical and psychosocial factors[7]) both of which determine an individual's capability to cope with environmental stresses.[7] As one gets older, the ability of his/her internal organs and systems to simultaneously resist environmental stresses and maintain homeostasis decreases.[4] Once certain debilitating factors reduce a person's stress tolerance to a level that leaves him/her incapable of confronting environmental pressure, his/her physical condition gradually declines such that he/she develops frailty and disability. Likewise, when a frail elderly person is continuously exposed to environmental pressure, he/she is in danger of gradually developing a disability owing to this prolonged exposure even though the environmental pressure is minor and poses no immediate life-threatening risks.[7]

Because the older adult population increases each year around the world, the corresponding population of frail elderly is also expanding proportionally. Thus, the overall cost of medical care and social welfare is increasing and becoming a burden for the society and the economy.[7] Owing to the increasing importance of characterizing the frailty syndrome, Fried et al.[2] have developed a set of assessment methods called Fried frailty

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criteria. These criteria are based on an assumption that a person's frailty results from the progressive decline of physiological functions in multiple systems of his/her body. To operationally define whether an elderly person is in the frailty stage, the following five criteria are needed: involuntary rapid weight loss, self-reported exhaustion, low physical activity, slow walking speed, and muscle weakness. An elderly person is considered to be in the frailty stage if he/she meets at least three of the five criteria, which surpasses the threshold standards. In addition, an elderly person is considered to be in the prefrail stage if he/she meets one or two criteria, which exceeds the threshold standards. Finally, an elderly person belongs to the "nonfrail group" or is in the "robust" stage if he/she does not meet any of the abovementioned criteria above the threshold standards, i.e., he/she does not show any signs of weakness.

Because the increasing number of elderly individuals has become an unavoidable trend in society, the current priority is to develop ability to correctly diagnose the "prefrail" stage for early detection and intervention of the frailty syndrome to inhibit functional deterioration.[8] It is essential to keep those individuals in the prefrail stage from transitioning to the frailty stage.[2,3] Therefore, the objectives of this study were to develop a new, automated, and computerized platform for the frailty assessment tools (FAT) system for the early detection of individuals who are in the "prefrail" stage and to compare the results of evaluating older adult population using the FAT system with the corresponding determination made by Fried frailty criteria, for identifying physical tests that can be effectively applied to predict the prefrail stage.

2. METHODS

The study protocol included three steps: (1) to develop the FAT system to perform appropriated physical performance tests; (2) to compare the screening results of the FAT system with the classification of Fried frailty criteria to identify the effective predictors of pre-frailty; and (3) to organize a quantified index indicating the frailty degree of elderly population.

2.1. Study design and elements

2.1.1. System framework

The concept of FAT system organization is based on combining appropriate physical performance examination tests into one computerized automatic screening platform, which includes specific sensors, measurement technology, and user interface. The data representing physical performance test results were collected, recorded, calculated, and analyzed. Meanwhile, Fried frailty criteria were programmed in advance, and the conditions of frailty status were judged and grouped automatically.

When considering mobility and portability, the elements of system hardware were designed to be quickly and easily disassembled and reassembled. In combination with a graphical user interface (GUI) software program written in NI LabVIEW that was executed on a laptop personal computer, the FAT system could provide visual and auditory feedback for elder subjects.

The entire system framework is shown as Fig. 1. During physical performance tests, signals detected by sensors were captured by a digital and analog data acquisition (DAQ) unit and transmitted via a universal serial bus (USB) port to the laptop PC. These signals were further converted by acquisition driver (NI DAQmx), calculated and managed by the NI LabVIEW software, and then shown to elder subjects in the form of sounds and lights. In addition, performance data were automatic recorded and saved in files.

2.1.2. Physical performance tests

The common physical performance tests used in previous studies were reviewed. Considering clinical applicability and time consumption, six physical performance tests for frailty screening were selected, as follows.

(1) Single leg standing (SLS) test

SLS test is a clinical tool to assess postural steadiness in a static position by quantitatively measuring the time of maintaining balance while standing on each leg without any support.

(2) Repeated chair rise test (RCRT), five times sit to stand test

RCRT measures how quickly one can stand from a chair and sit down five consecutive times.[9] This test has been widely used to identify people with and without balance/vestibular dysfunction[10] and identifying elderly subjects with postural instability and at high risk of falling.[10]

(3) Timed up and go (TUG) test

The test requires a subject to stand up, walk 3 m, turn, walk back, and sit down. Time taken to complete the test is strongly correlated with the level of functional mobility. Older adults who are able to complete the task in less than 20 seconds have been shown to be independent in transfer tasks involved in activities of daily living. However, older adults requiring 30 seconds or longer to complete the task tend to be more dependent in activities of daily living and require assistive devices for ambulation.[11]

(4) Gait speed, self-selected walking speed (SWS)

Gait speed indicates a multisystemic wellbeing; slow gait speed may suggest a subclinical impairment in health status. Gait speed measurement allows to detect adverse outcome of older people. In addition, it has been suggested that SWS is an appropriate standard clinical elderly evaluation tool among various walking speeds.[12]

(5) Functional reach test (FRT)

FRT is a common tool for evaluating the dynamic standing balance of elderly. The test is designed to assess anteroposterior (AP) stability by measuring the maximum distance that one can reach forward beyond arm length at shoulder height while standing over a fixed support base.[13–15] This test has been originally designed as a measure of limits of stability (i.e., center of pressure excursion[15]) and is valuable for identifying older people who are frail and who have a high risk for falls.[13]

(6) Grip strength/power (GP)

GP test determines the maximal grip force that can be produced in one muscular contraction.[16] It is convenient, safe, reliable, and does not require large or expensive equipment.[17] Consequently, this test has been used as an indicator of overall muscle strength[16–18] and is an accurate predictor of all causes of mortality in elderly persons.[19]

2.2. FAT system establishment

The FAT system consists of two parts: (1) a portable and automatic hardware and (2) a software with a visual and auditory human-machine control interface.

2.2.1. Hardware settings

The motion of subjects was captured and recorded by sensors and meters including four ON/OFF switches (each containing

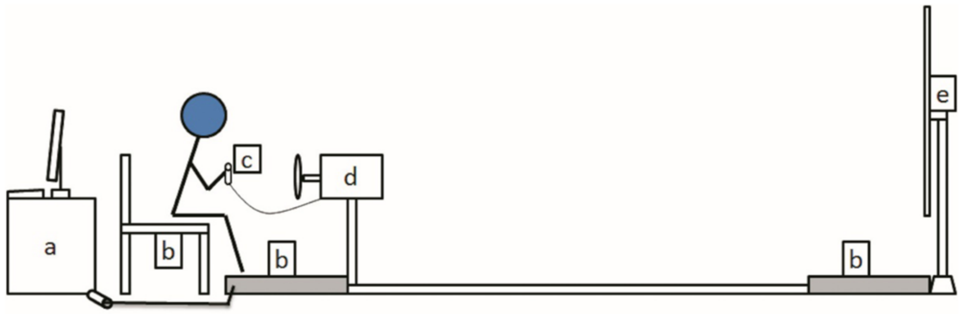

Fig. 1 Hardware setting of the frailty assessment tools system. (a) PC system with LabVIEW. (b) ON/OFF switches for posture change recognition for standing, sitting, leg lifting, and walking time counting. (c) Grip power measurement. (d) Functional reach distance meter. (e) Feedback for the participants.

four microswitches), one functional reach distance meter (linear wire potentiometer), and one GP meter (aluminum alloy handle with four strain gauges). Signals produced by physical performance tests were transmitted to the signal management center, which was mainly composed of a DAQ unit (NI USB-6009); then, the signals were transferred to a driver-mounted laptop PC.

In addition, one 3-m walkway, a standard armless chair, and a set of projector and display screen were accessory equipment to assist in performing tests.

2.2.2. Software program

The computerized testing program of the FAT system was developed with a graphic language software, NI LabVIEW 8.5 (National Instruments Corporation's Laboratory Virtual Instrument Engineering Workbench, 2007), which is a visual programming platform that is based on virtual instrument technology and GUI. When the software is connecting to specific sensors through hardware driver (NI DAQmx 8.9), it is possible to easily design a human-machine interactive program with visual and auditory feedback and obtain physical performance testing results quickly and accurately.

The FAT system software program included eight main function windows (data collection, SLS test, RCRT, TUG test, SWS measure, functional reach distance meter, GP measure, and comments), and several accessory subfunction modules (calibration, data acquisition, frailty grouping, save data, recall data, and play demo video) (Fig. 2).

2.2.3. Data processing and parameters

All voltage signals gathered from sensors were automatically calculated and transformed into physical performance test results. The result of the SLS test was the longest time among all four

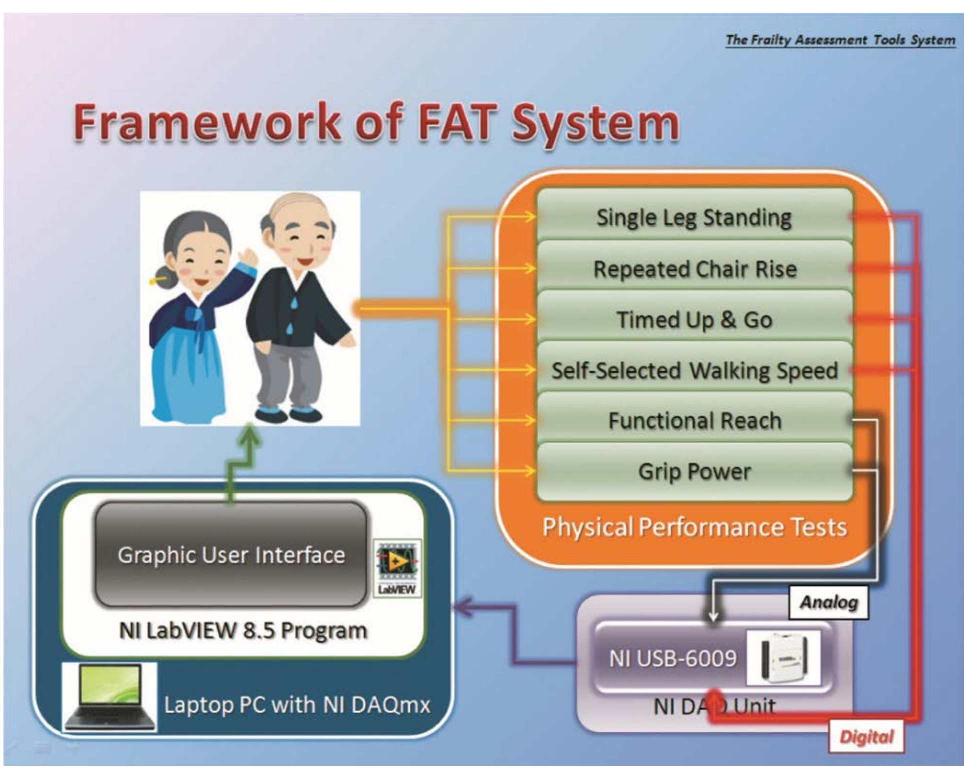

Fig. 2 Function window of the frailty assessment tools (FAT) system. The FAT system software program includes eight main function windows (data collection, single leg standing test, repeated chair rise test, timed up and go test, self-selected walking speed measure, functional reach distance meter, grip power measure, and comments) and several accessory subfunction modules (calibration, data acquisition, frailty grouping, save data, recall data, and play demo video).

trials (two for each leg).[20] The results of RCRT and TUG test were the average time of two trials.[21,22] The result of SWS was the fastest speed of four trials (two trials in each direction).[6] The result of FRT was the average body height-normalized[23–25] distance of three trials.[22] The GP test result was the best power of three trials.[2]

In addition, age, gender, and body mass index (BMI) were calculated and recorded. Except for the nominal variable age, all other parameters were continuous variables.

2.3. Characteristics of the prefrail early detection of FAT system

2.3.1. Participants

People over 65 years of age were randomized recruited in the Rehabilitation Department at a teaching hospital in New Taipei City. The exclusion criteria were as follows: inability to walk without assistance for 10 m, history of hip replacement,[5] inability to follow gestural or verbal commands,[26] or any changes in medications for at least 6 months before enrolling in the study. All subjects were instructed to read and sign a separate written informed consent form, with help of a family member when subjects had difficulty in reading. The study protocol was approved by the Institutional Review Board of National Yang-Ming University for medical morality and ethics to ensure personal safety and rights of participants in the experiment.

2.3.2. Experimental procedure

All screening examinations were indoor activities, and no special clothing or equipment was required on subjects' bodies. The sensors and meters were placed on the seat, walkway, or beside them to prevent interference with the progress of the experiment.

First, the subjects were instructed to sit well and watch a demonstration video played by the FAT program. Next, questionnaires about the date of birth, gender, height, weight, and dominant hand were completed by the participants. Six physical performance tests were performed in the orders of SLS, RCRT, TUG, SWS, FR, and GP. Sound and light were provided as auditory and visual cues during each physical performance test. There was a 3-minute break between each physical performance test to avoid interference effects between different tests. During the tests, computation and recording of data, and classification of frailty status were executed simultaneously. Finally, the FAT program showed test results and frailty group to be confirmed and subsequently saved.

2.4. Statistical analysis

Statistical package for the social sciences (SPSS Inc. Released 2008; SPSS Statistics for Windows, Version 17.0., SPSS Inc., Chicago) was used for statistical analysis. The significance level was set at 0.05 (α = 0.05). According to the study objectives, statistical analysis was partitioned into two steps, as follows (Fig. 3).

2.4.1. Difference in variables between prefrail and robust groups

To evaluate the prefrail detection by the FAT system, the parameters of prefrail and robust groups were compared to identify effective predictors of prefrailty. The χ^2 test was used to compare the only nominal variable, age. All other parameters, continuous variables, were first checked for normal distribution. Then, independent samples *t* test and Mann-Whitney *U* test were used to analyze normal and non-normal distributive variables, respectively.

2.4.2. Probability of elders of being prefrail

A binary logistic regression model was applied to identify a relationship between prefrail and physical performance test results. Independent variables were significantly different parameters between the two groups, and the dependent variable was group categories. The formula of the binary logistic regression model is

$$Z = \ln\left(\frac{P}{1-P}\right) = a + b_1(X_1) + b_2(X_2) + b_3(X_3) + \cdots,$$

where Z represents the statistic of episode occurrence; X_1, X_2, and X_3 are the predictors; α is the constant; b_1, b_2, and b_3 are the coefficients.

Furthermore, the probability of occurrence is obtained using the function

$$Probability = \frac{e^z}{1+e^z}.$$

3. RESULTS

3.1. Demographic data

A total of 35 elderly were recruited in our study. There were 21 males (mean age: 70.00 ± 6.09 years old; height: 165.86 ± 4.86 cm; body weight: 65.84 ± 9.37 kg; BMI: 23.99 ± 3.68 kg/m^2) and 14 females (mean age: 72.07 ± 5.05 years old; height: 150.54 ± 5.56 cm; body weight: 55.07 ± 10.30 kg; BMI: 24.16 ± 3.34 kg/m^2). The participants were categorized into three groups according to Fried frailty criteria, including the robust group (6 males/6 females), prefrail group (13 males/6 females), and frailty group (2 males/2 females). The mean age, height, weight, and BMI in each group are shown in Table 1. A total of 17 subjects were categorized into the prefrail group owing to the failure in five events of Fried frailty criteria; the event with the highest number of failures was GP (17 participants). The results of demographic data and examinations consisted of one nominal variable (gender) and eight continuous variables. After the analysis, only BMI, FRT, SWS, and GP data showed normal distribution. The BMI, gender, and age data did not show any statistically significant difference between prefrail and robust groups. Out of six physical performance tests, the robust group subjects performed better in RCRT, TUG, SWS, FR, and GP (Fig. 4). Statistical analysis showed significant differences between the prefrail and robust groups in the abovementioned five tests, and only SLT showed no significant difference (Fig. 5).

3.2. Formulation of the FAT score

Five continuous variables (RCRT, TUG, SWS, FRT, and GP) were significantly different between prefrail and robust groups. On the basis of the binary logistic regression model, the coefficients for five tests are shown in Table 2. Therefore, the logistic regression equation is written as follows:

$$Z_{Robust} = -80.857 + 0.188(RCRT) + 1.708(TUG) + 0.482(SWS) + 0.156(FRT) + 0.559(GP)$$

The probability that an elder belongs to the robust group is predicted as follows:

$$P_{Robust} = \frac{e^{Z_{Robust}}}{1+e^{Z_{Robust}}}$$

Thus, the probability of an elder belonging to the prefrail group is determined by the "prefrail prediction equation", which is represented as:

$$P_{Prefrail} = 1 - P_{Robust} = 1 - \frac{e^{Z_{Robust}}}{1+e^{Z_{Robust}}} = \frac{1}{1+e^{Z_{Robust}}}$$

Using this equation, the probability of each subject being a prefrail elder can be obtained after performing five physical performance tests. In our study, we defined this percentage value as

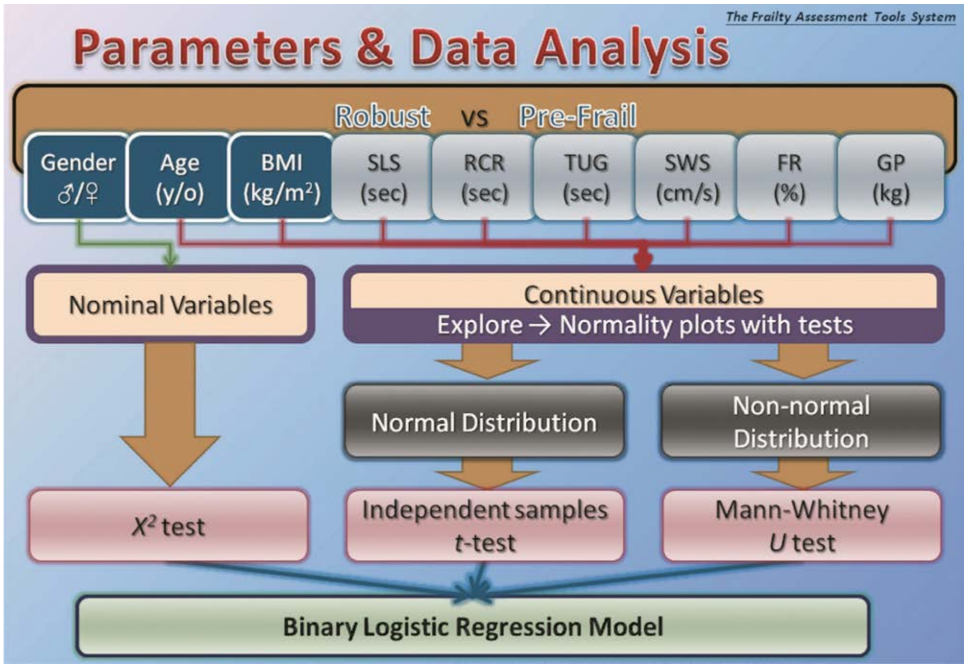

Fig. 3 Parameters and data analysis. FR = functional reach; GP = grip power; RCR = repeated chair rise; SLS = single leg standing; SWS = self-selected walking speed; TUG = timed up and go.

a quantifiable index, the "FAT score." The average FAT scores of prefrail and robust groups were 90.73 ± 19.95% and 15.01 ± 25.25%, respectively. This means that the average chance of our prefrail subjects to be in the prefrail stage was approximately 90.73%; thus, they had a 90.73% likelihood to be in danger of prefrailty, or the average degree of prefrailty severity was 90.73%, while the average degree of danger of prefrailty or prefrailty severity of robust subjects was relatively low, only approximately 15.01%.

4. DISCUSSION

4.1. Advantages of the FAT system

Our experimental results showed that in conjunction with five physical performance tests, the computerized FAT system is capable of effectively predicting whether an elderly person is entering the prefrail stage. Whether the prefrail stage is reached is a key index for determining intervention for the frailty syndrome at an early stage. Therefore, the physical performance tests employed by this system can sensitively detect the early signs of the frailty syndrome. Once the system is more fully developed, we will be able to quickly understand the worst aspects of physical performance of an elderly patient from frailty screening and thus immediately design a relevant regimen of rehabilitation exercises. This process will facilitate the healing of his/her deficiencies, which will avoid the deterioration and block the occurrence of frailty. This aspect of our system is essential for the rehabilitation of older adults.

Compared with traditional detection methods, the computerization of physical performance tests (along with automated measuring equipment) has many clear advantages. The new method avoids various mistakes that may easily result from manual measurements and questionnaire surveys. In addition, this method has high detection accuracy and low error rate, both of which are essential elements for future large-scale screening for the frailty syndrome. Finally, this system relies on a user-friendly human-computer interactive interface, which is designed by the virtual instrument software LabVIEW, which uses sound and light to build an environment that is capable of generating instantaneous feedback regarding test results. Such setup promotes curiosity and interest in older adult subjects, increases their willingness to participate, and strengthens awareness and concern about their health status.

To achieve the goal of correctly identifying frail population, the first task is to compile a comprehensive database for the frailty syndrome. However, this process will likely consume a considerable amount of time and manpower if the abovementioned

Table 1

Demographic data of groups

	Male (N = 21)				Female (N = 14)			
		F (n = 2)	P-F (n = 13)	R (n = 6)		F (n = 2)	P-F (n = 6)	R (n = 6)
Age, y/o	74.00 (6.09)	70.50 (3.54)	75.08 (6.34)	72.83 (6.31)	72.07 (5.05)	74.50 (6.36)	73.33 (3.44)	70.w00 (6.07)
Body height, cm	165.86 (4.86)	172.50 (0.71)	165.88 (4.76)	163.58 (4.01)	150.54 (5.56)	146.50 (4.95)	151.75 (5.78)	150.67 (5.82)
Body weight, kg	65.84 (9.37)	67.50 (3.54)	66.38 (10.35)	64.10 (9.29)	55.07 (10.30)	46.50 (4.95)	59.83 (10.26)	53.17 (10.23)
BMI, kg/m^2	23.99 (3.68)	22.69 (1.37)	24.23 (4.26)	23.91 (3.08)	24.16 (3.34)	21.63 (0.84)	25.83 (2.89)	23.35 (3.71)

Standard deviation is in the parentheses.
BMI = body mass index; F = frailty; P-F = prefrail; R = robust.

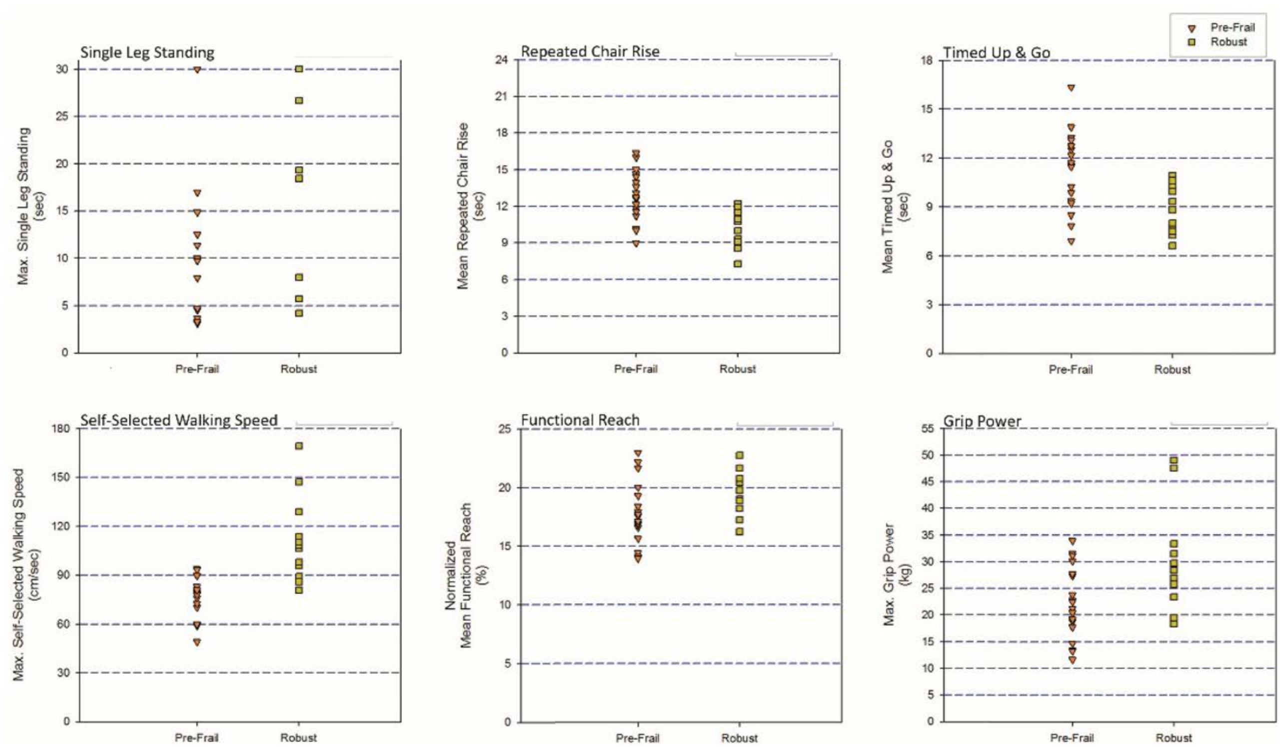

Fig. 4 Scatter plot showing the data from six physical performance tests of pre-frail and robust groups. The subjects categorized in the robust group performed better in repeated chair rise test, repeated chair rise, self-selected walking speed, functional reach, and grip power.

computerized system is not used, which can perform all tests within an average of 17 minutes. Thus, our system allows to efficiently use time and also spares considerable manpower owing to the process of automatic detection. Eventually, this system will accelerate the establishment of frailty database and lower the requirements for specialists and cost of purchasing expensive

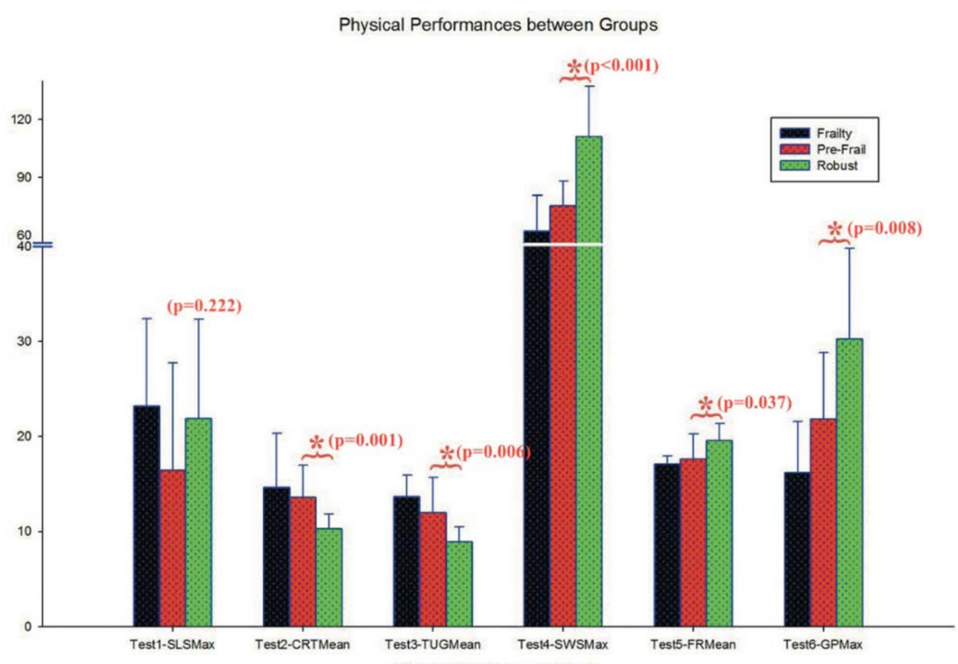

Fig. 5 Six physical performance tests. Using independent *t*-test and Mann-Whitney *U* test, single leg standing test (SLS) showed no significant difference between robust and prefrail groups. Repeated chair rise test (RCRT), timed up and go test (TUG), self-selected walking speed (SWS), functional reach test (FR), and grip power (GP) showed significant differences between robust and prefrail groups, which were applied to the frailty assessment tools formulation for predicting prefrailty. *Significant difference between prefrail and robust groups at $p < 0.05$.

Table 2

Binary logistic regression analysis

Variables	*B*	SE	Wald	*p*	Exp(*B*)
T2CRTMean	0.188	0.753	0.062	0.803	1.207
T3TUGMean	1.708	1.299	1.728	0.189	5.515
T4SWSMax	0.482	0.315	2.346	0.1226	1.620
T5FRMean	0.156	0.434	0.129	0.719	1.169
T6GPMax	0.559	0.473	1.397	0.237	1.750
Constant	–80.857	54.706	2.185	0.139	0.000

B = estimated value; *p* = significance; SE = standard error.

equipment. In addition, the computerized assessment platform can be operated at high speed. Therefore, once the test information for a subject is obtained, the system rapidly performs frailty status evaluation via computation and data comparison and proposes a diagnosis.

4.2. Necessity of early intervention for the frailty syndrome

Some scholars have argued that to prevent various unfavorable consequences of social costs caused by frail elderly population, the top priority should be to establish appropriate methods and tools to clinically assess the frailty syndrome. This capability will allow to identify groups at risk of becoming frail, which subsequently provides these individuals with intervention and treatments via multidimensional and interdisciplinary approaches.[7] In addition, most scholars believe that the weakening of an elderly person is a continual process in which he/she gradually transitions from the normal aging state to eventual disability or death. This process is further divided into "prefrail" and genuine "frail" stages.[8] For those elderly exhibiting risk factors, intervention during the first stage is necessary to prevent him/her from developing the frailty syndrome (i.e., from entering the prefrail stage). Intervention during the second stage must be undertaken at the immediate onset of the syndrome to reverse the process and prevent continued functional deterioration.[8]

The rapid functional advancement of personal computers provides a powerful method and extension to peripheral equipment. In addition, various network technologies have been developed, producing an even faster transmission speed. If our system can be integrated with the current network transmission technology, test data will be instantaneously transferred to a physician or a laboratory technician to serve as a reference for clinical intervention. Thus, our system allows to make an "immediate diagnosis" and can also achieve the goal of an "instant alert." Eventually, the establishment of frailty database will be accelerated.

The hardware of our system platform can be easily assembled and disassembled, which allows the operators to conveniently move between testing sites. Thus, rather than restricting the operation to a clinic or laboratory, frailty syndrome screening tests can be performed on a much larger scale and for a larger population, which allows to establish a more comprehensive frailty syndrome database.

Considering the aforementioned advantages, the FAT system is an excellent screening setup that is capable of replacing traditional manual measurement and assessment tools.

4.3. Additional study on frailty indicators

The Fried frailty criteria contain five indicators, three of which are part of a questionnaire survey, whereas the remaining two are based on physical performance tests (i.e., "free walking speed" and "GP"). The two physical tests are also included in the six physical performance tests of our FAT system. Therefore, as expected, the analysis of results from this experiment indicates that the scores from "free walking speed" and "GP" tests are effective indicators of the prefrail stage. Among other physical performance tests, only the "SLS test" does not meet the standard revealed by verification experiments. However, this parameter is measured over a 30-second period, which may cause a ceiling effect and decrease the correlation between the parameter and frailty. In addition, on the basis of physiological function, the "SLS test" mainly examines the posture of an elderly patient, whereas the frailty phenomenon is more associated with the overall physical endurance. Therefore, the relevance of this examination is not as high as that of the other tests.

At its origin, the frailty syndrome is a multidimensional and multisystemic aggregate phenomenon. Thus, the definition and diagnosis of this syndrome must be determined from different aspects, including the performance of physical functions, psychological health, assessment of mental status, blood biochemistry of the endocrine system, and nutrition status. However, this study aims to develop a set of quick screening tools to allow clinicians to choose between various assessment methods. Because systemic aspects leading to frailty can interact with each other and because the loss of physical performance is the final presenting consequence owing to the interaction of various systems, this study measured performance to screen for the frailty syndrome.

Nevertheless, "rapid weight loss" is also a condition stemming from the interaction of multiple systems, and it is likely associated with abnormal nutritional status and reduced activity. Thus, weight loss is a potential parameter.

4.4. Quantification of frailty: FAT score

To combat the frailty syndrome, scholars have proposed that it is necessary to provide sports and medical intervention to prefrail elderly individuals to prevent further progression into the frailty stage. However, we argue that it may be possible to expand the scope of prevention. Instead of limiting intervention to prefrail patients, subjects in the first stage should include all elderly individuals with frailty risk factors. Thus, nonfrail elderly who are potentially at risk of frailty, as revealed by screening, are also suitable subjects for early intervention. However, even older adults within the same prefrail stage exhibit varied levels of frailty, and Fried frailty criteria unfortunately cannot be used to identify differences in the frailty level for elderly patients in the same group.

In the results and analysis of this research, a "prefrail prediction equation" developed via a binary logistic regression model was used to calculate the probability of whether an elderly subject who was not in the frailty group (i.e., in either prefrail or nonfrail groups) belonged to the prefrail group. This probability represents the chance that an elderly patient is gradually progressing into prefrailty from nonfrailty. Specifically, the probability deduced from the equation indicates the deterioration rate or risk level of an older adult patient for transitioning from the nonfrail stage to a prefrail stage. In this study, such probability is referred to as the "FAT score." On the basis of the definition of the FAT score, we can calculate the severity and deterioration rate for an elderly person who has not entered the frailty stage and provide them with quantitative data to create intervention strategies during the first stage of prefrailty. Therefore, elderly patients with different FAT scores will receive intervention strategies. For example, an elderly patient with a high FAT score (owing to his/her severity of frailty and rapid deterioration rate) will receive aggressive intervention, whereas someone with a low FAT score (owing to his/her lower level of frailty and relatively slow rate of progression) will be suggested observation or monitoring. Likewise, for an elderly patient with an intermediate FAT score, ordinary intervention strategies can be employed. Thus, the use of more precise intervention strategies based on different FAT scores can effectively help avoid wasting medical resources, increase the proper use of social welfare, and reduce overall spending.

During the research, one coincidental event demonstrated the ability of the FAT score to predict prefrailty. Specifically, one of the subjects started to suffer from a pontine infarction during the seventh month after the start of screening with our system. Nevertheless, at the beginning of screening, Fried frailty criteria indicated that the subject belonged to the nonfrail group, which in theory should not be associated with such a severe health problem. However, according to the FAT score prediction, the probability of this individual to develop prefrailty was 46.88%, which was considerably higher than the average score of other members of the nonfrail group (15.01%). On the basis of this score, a subject should be monitored closely and should even receive intervention if necessary. This case illustrates the main point of the FAT system, which aims to identify any potential risk group at an early stage.

4.5. Experimental limitation

One limitation of this study is the insufficient sample size of subjects. In the experimental results that are based on a binary logistic regression model, four predictors of the prefrail stage were identified and used to develop the "prefrail prediction equation," which allowed to calculate the FAT score to represent the degree of frailty of an elderly patient. However, during the statistical analysis, these predictors failed to reach significance. A possible explanation is the inadequate experimental sample size, which was even smaller after the division into subgroups. The largest group (prefrail group) had only 19 subjects. Thus, the small sample size reduced the statistical power of individual predictors.

This study may also suffer from sampling bias. Among 35 elderly subjects recruited by the research institute, only four belonged to the frailty group, as determined by Fried frailty criteria. Therefore, the frailty group was significantly smaller than prefrail (19 subjects) and nonfrail (12 subjects) groups. Regarding the age distribution of the subjects, only five subjects were over 80 years old, which accounted for only 14.29% of the total subjects. For the extremely old age group, there was only one subject who was over 85 years of age. This age distribution was possibly due to the study being conducted in clinics. Because it is common for frail or extremely aged elderly persons to have mobility disabilities/difficulties, they are less likely to participate in a study such as this one. In addition, because the subjects were mainly from clinics, most of them were afflicted with various levels of orthopedic issues. Another possible limitation is that the subjects in this study were all of standard weight or were overweight, and there were no obese individuals.

Finally, the "GP" test in Fried frailty criteria was another potential limitation. The threshold that we used was based on data from studies in foreign countries. Compared with the ordinary GP of Chinese elderly, this threshold was approximately equal to the average score of all older adults.[27] Thus, this threshold was relatively high for evaluating the GP of Chinese elderly patients, which resulted in a low passing rate in the GP test. Therefore, on the basis of the index of GP, we may have overestimated the proportion of subjects who were considered frail.

Although academic and geriatric researchers currently offer conflicting and confusing opinions regarding the assessment, diagnosis, and clinical definition of the frailty syndrome, the initial consensus has been reached regarding the long-term impact of the frailty syndrome and its importance for the overall social health care. The only way to delay or block the frailty syndrome is to have experts from various areas collaborate to employ appropriate methods to effectively assess and diagnose, conduct swift screening and detection, and provide early intervention and treatment. These combined efforts will help minimize the negative effects and damage resulting from the frailty syndrome.

In this study, we developed a computerized form of six common physical performance tests for the frailty syndrome, which formed a screening assessment platform with a set of audiovisual animations and interactive feedback; this platform is not limited by test location. The test results of prefrail and nonfrail groups were compared to develop an equation (i.e., prefrail prediction equation) that governs individual functional tests and different frailty groups. On the basis of the scores of functional tests, the FAT scores of elderly subjects can be calculated. Then, these scores can represent the degree of frailty and rate of progression and serve as the basis for therapeutic intervention strategies.

In the future, we anticipate that more comprehensive and representative physical function performance tests will be added to promote the ability to assess individuals with the frailty syndrome. In addition, more elderly subjects are needed to participate in screening tests of the frailty syndrome to establish a more comprehensive frailty syndrome database and better understand the occurrence and distribution of this disease among the older adult population. Further studies will contribute to the effective utilization of social welfare, resources, and funding.

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