Sit-to-stand movement score and locomo-age to detect locomotive syndrome in older adults

Go Yamako (g.yamako@cc.miyazaki-u.ac.jp)
University of Miyazaki
Niroshan G. Punchihewa
University of Miyazaki
Hideki Arakawa
University of Miyazaki
Takuya Tajima
University of Miyazaki
Etsuo Chosa
University of Miyazaki

Research Article

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Abstract

Background Aging is characterized by biological changes, such as reductions in muscle strength and the loss of mobility and balance. The Japanese Orthopaedic Association proposed the term “locomotive syndrome” (LS) to define people at risk of requiring nursing care because of problems with locomotive system. A need exists to develop simple methods to quantify motor performance and allow the early detection of LS. Sit-to-stand (STS) movements are a mechanically demanding daily task and represent motor performance. Using the Nintendo Wii Balance Board (WBB), we have developed a novel method to quantify STS movements—the “STS score.” This study investigated differences in the STS score across LS severity in healthy older adults. To recognize motor performance easily, we then defined the “locomo-age” to represent the individual’s age based on the LS status.

Methods We investigated whether the STS score can predict LS. This study enrolled 152 participants of 65 years and above. Participants were divided into three groups based on LS risk test results. Participants were instructed to stand up as quickly as possible on the WBB, and the STS score was calculated based on the combination of the speed and balance indices. We also evaluated motor status by calculating the peak power during STS and performing a timed up and go test and handgrip strength test. To calculate locomo-age, we used a regression equation between STS scores and age from a data set in our previous study.

Results The LS stage was increased significantly with age, whereas the association with body mass index was not significant. The STS score and timed up and go results were good indicators to detect LS. However, neither peak power nor handgrip strength could significantly distinguish between the LS stages.

Conclusions Measurement of the LS is important to assess older adults’ motor performance. The novel STS score is an easy-to-use method that requires limited space and only one person to operate. The STS score decreased significantly with the LS severity and thus could be used to assess LS in older adults. The locomo-age of the STS score is useful to understand the LS status.

Background

Aging is characterized by biological changes, such as reductions in muscle mass and strength and the loss of mobility and balance [1]. This physiological deterioration leads to difficulties in performing activities of daily living (ADLs), and consequently, a decrease in the quality of life (QOL). In 2007, the aging rate in Japan exceeded 21%, and the country is now facing a “super-aged” society. The Japanese Orthopaedic Association (JOA) thus proposed a new term—“locomotive syndrome” (LS)—to define individuals at risk of requiring nursing care services because of difficulties in living independently as a consequence of problems in locomotive organs, such as muscles, bones, and joints [2]. To improve the QOL of older adults, the JOA promotes physical exercise training and developed a risk test for LS based on the 25-question Geriatric Locomotive Function Scale (25-question GLFS), two-step test, and stand-up test [3]. The LS risk test is now used to screen a decline in motor performance [4]. However, this test is time consuming (more than 5 minutes per test-taker), and it requires a large space (more than 12 m^2) and sufficient staff (more than 3 individuals) to perform the test safely. The 25-question need a long time to complete and the response rate is low in older people [5]. For most clinics, these requirements limit the use of the LS risk test on a daily basis. These issues motivated us to develop new methods to easily and quantitatively evaluate motor performance to identify the decline in mobility and LS.

We have thus developed a new method to evaluate motor performance based on sit-to-stand (STS) movement [6]. The STS movement is quantified by the STS score, defined as a combination of the speed and balance parameters using the vertical ground reaction force (VGRF) and center of pressure (COP) data measured from the Nintendo Wii Balance Board (WBB; Nintendo, Kyoto, Japan). Our previous study demonstrated that the STS score can detect age-related deterioration in motor performance based on data from 503 healthy individuals aged 20–88 years, without musculoskeletal or neuromuscular disorders [6]. In ADLs, STS movements are important tasks; a decreased ability to perform this movement is associated with falling [7], hip fracture [8], and institutionalization, or even death [9]. In addition, the STS movement has been identified as mechanically demanding because this action requires significant muscle strength, a wide joint movement, and good balance control [10, 11]. Accordingly, age-related decreases in muscle strength and balance control are associated frequently with difficulties in completing STS movements [12–14]. Thus, STS movement has been identified as a valuable source of an individual's motor performance [14–18].

We thus hypothesized that the STS score can predict the LS status. This study investigated differences in the STS score across the range of severity of LS in healthy older adults. In addition, we evaluated whether the performance of the timed up and go (TUG) test and the handgrip strength test could predict the LS status. Finally, we defined "locomo-age" as an individual's age represented by the LS status based on the regression curve of the STS score.

Methods

Participants

A total of 152 healthy participants older than 65 years (age range, 65–88 years; male/female ratio, 59:93) were recruited from local senior citizen clubs (called *rojin* clubs in Japanese). None of the participants had any known musculoskeletal or neuromuscular conditions that would limit their mobility or their ability to perform the STS movement. Research protocol of this study followed the Declaration of Helsinki. The ethical committee of our university approved the study protocol (reference number: 2014–231), and all participants provided written informed consent.

LS Risk Test to Classify LS Grade

The participants were categorized into three groups according to the severity of LS, determined by the LS risk test [3, 19]. The LS risk test consisted of three parts: (1) the 25-question GLFS, (2) the two-step test, and (3) the stand-up test.

(1) The 25-Question GLFS

This scale is a self-administered, comprehensive measure, consisting of 25 items that include 4 questions on pain, 16 questions on ADLs, 3 questions on social functions, and 2 questions on mental health status. Each question is graded with a 5-point scale, from no impairment (0 points) to severe impairment (4 points). Participants are scored for a total by adding the points for each question (minimum = 0; maximum = 100 points). Thus, a higher score is associated with decreased mobility performance.

(2) Two-Step Test

This test measures the stride length to assess walking ability, including muscle strength, balance, and flexibility of the lower limbs. The procedure is as follows. Participants were instructed to take two long steps, as long as possible, and then to align both feet. The score is calculated by normalizing the maximal length of the two steps taken by the participant based on the participant's height.

(3) Stand-Up Test

This test assesses leg strength. Participants stand up on one leg or both legs from decreasing a chair height from 40 to 10 cm, with a 10 cm stepdown. Lowering the chair height leads to a greater biomechanical demand while standing up from a seated position. Participants were instructed to stand up on one leg or both legs from each chair height without leaning back and then maintain the standing posture for 3 seconds. They were scored based on their height level using one leg and both legs. Scores ranged from 0 to 8 depending on their difficulty in standing up [4].

After these tests, participants were diagnosed by their severity of LS, either non-LS or stage □ or □, based on the JOA protocol [20]. Stage □ LS represents the beginning of the decline in mobility. An individual who cannot perform a one-leg stand-up movement from a seat 40 cm high, or whose 25-question GLFS score is ≥ 7, or whose two-step test score is < 1.3 is diagnosed with stage □ LS. Stage □ LS represents progression to a decline in mobility. An individual who cannot perform a both-leg stand-up movement from a seat 20 cm high, or whose 25-question GLFS score is ≥ 16, or whose two-step test score is < 1.1 is diagnosed with stage □.

STS Score

Details of the STS testing procedure were described in our previous study [6]. Participants were instructed to stand up from a chair as quickly as possible, immediately recover their balance, and stand as still as possible in an upright posture for 5 seconds. To perform this test, participants were seated on an armless, backless chair, with the seat height adjusted to 100% of the participant's knee height (Fig. 1). The participants crossed their arms over their chest during testing. Both feet were placed shoulder-width apart on the WBB that was used as a force plate. The WBB is designed to serve as a video game controller that is increasingly used to assess postural control in rehabilitation [21–26]. The WBB, which consists of a rigid platform with four strain gauge-based vertical-load transducers located in the feet at each corner, was used to calculate the VGRF and COP. During each STS movement, WBB data were streamed to a laptop computer at approximately 100 Hz. Before data were recorded, each participant was allowed the opportunity to practice the procedure. Each participant performed two trials, separated by a 1minute interval. We did not observe any accidents, such as falling, during this test.

The STS score, which represents motor performance, was defined as a combination of the speed and balance scores. These parameters were calculated using the VGRF (in N), COP position in X and Y directions (Cx, Cy; in cm), and COP trajectory distance (in cm) during STS movement (Fig. 2). The VGRF was normalized to the participant's body weight. The speed score (s^{-1}) was defined as a linear slope of the VGRF–time curve. The balance score (m^{-1}) was defined as the inverse of COP trajectory distance when *Cy* was minimized to + 3 seconds. The STS score ($(ms)^{-1}$) was then defined as the product of the speed and balance scores to quantify STS movement performance. Higher STS scores indicated better motor performance. These two indices have a tradeoff relationship because typically if the movement speed (speed score) increases, it becomes difficult to control balance and remain as still as possible (balance score).

Indices were calculated from each set of trial data using a custom MATLAB program (MathWorks, Natick, RI, USA). For each participant, a practice trial was followed by two timed trials, and the average value was used as a result for further analysis.

Peak Power during STS

We all calculated the peak power during the STS movement using the WBB data. All ADLs require the body's center of mass to move from one place to another by producing adequate force from the muscles. Explosive power is proven to be a good indicator to identify the functional ability of aging people [27]. The rising phase during STS was detected based on the VGRF [28]. Power during this period was calculated by integrating the acceleration derived by the VGRF (velocity) followed by taking the scalar product of the force and velocity [29].

TUG Time

The TUG test, a well-known clinical test, was developed to improve evaluations of functional performance and mobility [30]. This test measured the time needed for a participant to rise from a chair, walk 3 m, turn around, walk back, turn around, and sit down again. A shorter TUG time indicates better performance. Participants were instructed to walk as quickly and safely as possible. For each participant, a practice trial was followed by two timed trials, and the fastest trial was selected for further analysis.

Handgrip Strength

Handgrip strength is a good index to positively correlate with motor function and ADL performance [31]. The strength was measured bilaterally in a standing position using a handgrip dynamometer. Both hands were tested two times, and the maximum value was used to characterize the participant's handgrip strength.

Statistical Analyses

Statistical analyses were performed using SPSS 22.0 (IBM SPSS, Chicago, IL, USA). One-way analysis of variance and the Dunnett T3 multiple comparison test were used to analyze the differences among the three groups, as defined by the severity of LS (non-LS, stage □ LS, stage □ LS). A p value of < 0.05 was considered statistically significant.

Results

Baseline Characteristics of Enrolled Participants

Among the 152 participants, 120 participants (78.9%) were diagnosed with LS (Table 1). The percentage of participants with non-LS was 19.8%, stage □ LS was 42.1%, and stage □ LS was 38.1%. The severity of LS increased significantly with age among participants ($p < 0.001$). No significant difference was noted in the body mass index among the three groups ($p = 0.296$). The results of the LS risk test, including the 25-question GLFS, two-step test, and stand-up test, are shown in Table 1.

Table 1
Demographic Data and LS Risk Test Scores for Each LS Stage

Demographic Data	**Non-LS**	**Stage □ LS**	**Stage □ LS**
Number (male/female)	30 (17/13)	64 (28/36)	58 (14/44)
Age, yr	71.5 ± 5.1□	75.8 ± 5.1□	78.8 ± 5.1□
Body mass, kg	55.5 ± 8.8	56.8 ± 9.7	54.2 ± 9.5
Height, cm	156.5 ± 8.7□	154.8 ± 8.6□	150.2 ± 7.8□
Body mass index	22.6 ± 3.0	23.6 ± 2.9	24.0 ± 3.6
25-Question GLFS	1.9 ± 1.7□	5.8 ± 4.2□	21.4 ± 15.5□
Two-step test	1.47 ± 0.09□	1.31 ± 0.11□	1.14 ± 0.15□
Stand-up test	5.3 ± 0.5□	4.0 ± 0.8□	3.2 ± 1.1□

Values are presented as the mean ± standard deviation. Roman numerals in superscripts (□–□) next to the data indicate the results of the post hoc analysis. The same numeral indicates no significant difference between the two groups; different numerals indicate a significant difference between the two groups ($p < 0.05$).

LS = locomotive syndrome, GLFS = Geriatric Locomotive Function Scale.

STS Score

During STS movement, similar curves for the VGRF, COP position, and trajectory were obtained for each group (Fig. 3). At the start of STS movement, the VGRF decreased because of hip flexion. Then, hip and knee extensions start and the VGRF reaches a peak value and oscillates around the body weight. Within 3 seconds from the start of the STS movement, the oscillation disappeared and the total COP distance was substantially stable (although not a plateau). Similar waveforms were observed among the groups, but differences were noted in the STS, speed, and balance scores (Table 2).

Table 2
STS Score, STS Power, TUG Time, and Handgrip Strength among LS Grades

Measure	Non-LS	Stage Ⅰ LS	Stage Ⅱ LS
STS score, $(\mathrm{ms})^{-1}$	34.1 ± 10.1	28.8 ± 8.6	24.3 ± 8.7
Speed score, s^{-1}	9.5 ± 2.3	8.5 ± 2.2	6.9 ± 1.7
Balance score, m^{-1}	3.6 ± 0.7	3.4 ± 0.8	3.5 ± 0.8
Peak power, W	391.7 ± 104.5	378.1 ± 98.9	369.2 ± 90.7
TUG time, s	5.3 ± 0.8	6.4 ± 1.0	7.6 ± 1.5
Handgrip strength, N	30.2 ± 8.6	26.3 ± 7.9	21.1 ± 6.4

Values are presented as the mean ± standard deviation. Roman numerals in superscripts (□–□) next to the data indicate the results of the post hoc analysis. The same numeral indicates no significant difference between the two groups; different numerals indicate a significant difference between the two groups ($p < 0.05$).

LS = locomotive syndrome; STS = sit to stand; TUG = timed up and go.

The STS and speed scores could differentiate among the three groups (both $p < 0.001$). The STS score decreased significantly with the severity of LS. A significant difference in the speed score was noted between non-LS, stage Ⅰ LS, and stage Ⅱ LS. The speed score decreased with increasing LS grade. However, for the balance score, no significant differences were observed ($p = 0.408$).

TUG Time, Handgrip Strength, and Peak Power

The TUG time increased significantly according to the severity of LS. For handgrip strength, no significant difference was noted between non-LS and stage I LS or stage II LS. The peak power decreased when the LS grade increased. However, no significant differences were observed.

Discussion

Prevention of the development of LS and deterioration in motor performance are crucial to maintain the QOL in older adults. Simple indicators are needed to estimate individual physical performance and mobility for the early detection of LS. The STS score was developed to quantify STS movement based on the speed and balance parameters because STS movement changes over time as people grow older, resulting in a loss of balance control and muscle strength. This study demonstrated that the STS score decreases significantly according to the severity of LS in individuals older than 65 years. The STS score may be used to screen LS. We thus defined a “locomo-age” that describes an individual’s age represented by their LS status. The locomo-age can be calculated from a regression equation between STS scores and age. The quadratic curve equation could be determined by a regression model based on the mean STS score and mean age in each of the seven 10-year age groups from 503 healthy individuals aged 20–88 years (Appendix A) [6]. Using this equation, the individual’s STS score can be converted to the locomo-age. If the individual’s locomo-age is higher than their age in years, then the individual would be at risk of developing LS. Thus, the locomo-age enables an individual to recognize their LS status more easily.

We used the STS score that was defined as a combination of the speed and balance scores, with the intention to quantify performance of STS movement using the VGRF and COP from the WBB. Our results showed significant decreases in the speed score with the development of LS. In contrast, the balance score could not differentiate the severity of LS. This finding implies that participants with a decline in motor performance must decrease their movement speed to maintain dynamic balance to accomplish STS movement more safely. These results emphasize the importance of combining both speed and balance parameters to evaluate the motor status. In fact, gait needs dynamic balance, and the gait speed decreases with age [32].

The TUG time was also good indicator to detect the LS status. This time seems to be a more significant parameter because the test includes walking, standing up, turning, stopping, and sitting down. However, the TUG test also needs a trained operator, such as a physiotherapist, and large space [33].

Although the handgrip strength served as an independent predictor to assess ADL performance, it is not a useful measurement to evaluate lower-extremity strength [34]. Our results further validate that the handgrip strength test is not suitable to detect early LS (stage □). Power has been demonstrated to be an early and potent marker of frailty [28]. In this study, the peak power could not detect LS in older adults. These results indicate that the simple muscle strength measurements may not be suitable to evaluate LS.

Several limitations of this study should be addressed. First, as we recruited participants from Japanese *rojin* clubs, these individuals may have been health conscious and may have had better motor abilities than the general population. It is necessary to conduct further studies that include members of the general population from defined regions. Second, a larger sample size is needed to analyze the cutoff value for LS.

Conclusions

Our results demonstrated a significant difference in the STS score across the range of severity of LS in participants older than 65 years. This simple and quantitative approach to quantify STS movement may be potentially useful as a tool to screen LS in older adult populations. In addition, we proposed the locomo-age to represent the individual’s age for their LS status. Further studies are needed to elucidate the cutoff values of the STS score for the LS stages.

Abbreviations

ADLs: activities of daily living; COP:center of pressure; GLFS:Geriatric Locomotive Function Scale; JOA:Japanese Orthopaedic Association; LS:locomotive syndrome; QOL:quality of life; STS:sit-to-stand; TUG:timed up and go; VGRF:vertical ground reaction force; WBB:Wii Balance Board.

Declarations

Ethics approval and consent to participate

Research protocol of this study followed the Declaration of Helsinki. This study was approved by the ethics committee of the University of Miyazaki (reference number: 2014–231). All the participants read and the understood the study protocol and a written informed consent was obtained prior to the experiment.

Consent for publication

Written informed consent was obtained to publish the images.

Availability of data and material

All data are available from the corresponding author upon request.

Competing interest

The authors declare that they have no competing interests. They declare that they have no financial or personal relationships with any other people or organizations that could have inappropriately influenced or biased this work.

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Authors' Contribution

GY designed the study and collected data, GY and NGP analyzed data and drafted the initial manuscript, HA helped data collection and data attraction, TT and ES developed the research question and guided the study. The authors read and approved the manuscript before submission.

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Figures

Figure 1

Sit-to-stand (STS) movement test. The Wii Balance Board is placed under the feet.

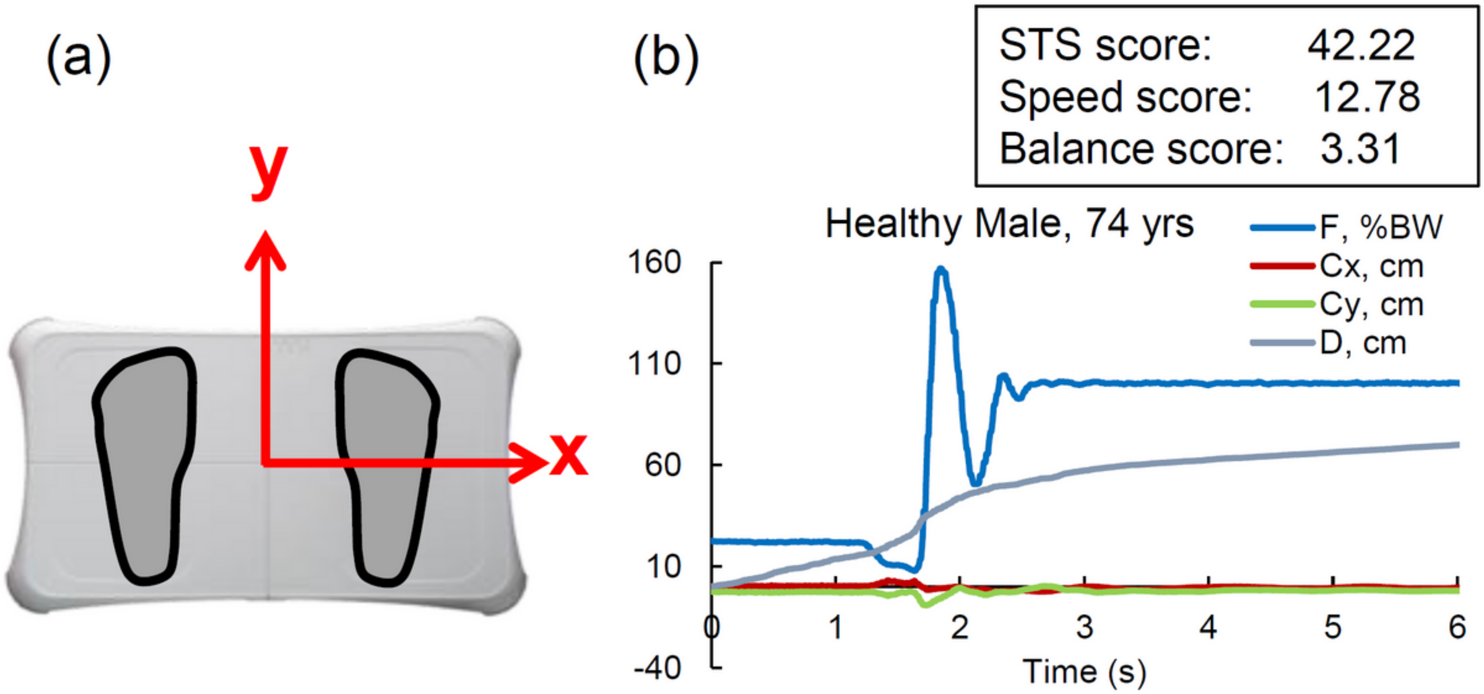

Figure 2

(a) Coordinate system of the Wii Balance Board and (b) a typical graph of the sit-to-stand (STS) test performed by a healthy person. The vertical ground reaction force (F) normalized by the body weight (BW) and center of pressure (COP) in the X (Cx) and Y (Cy) directions are plotted in the graph.

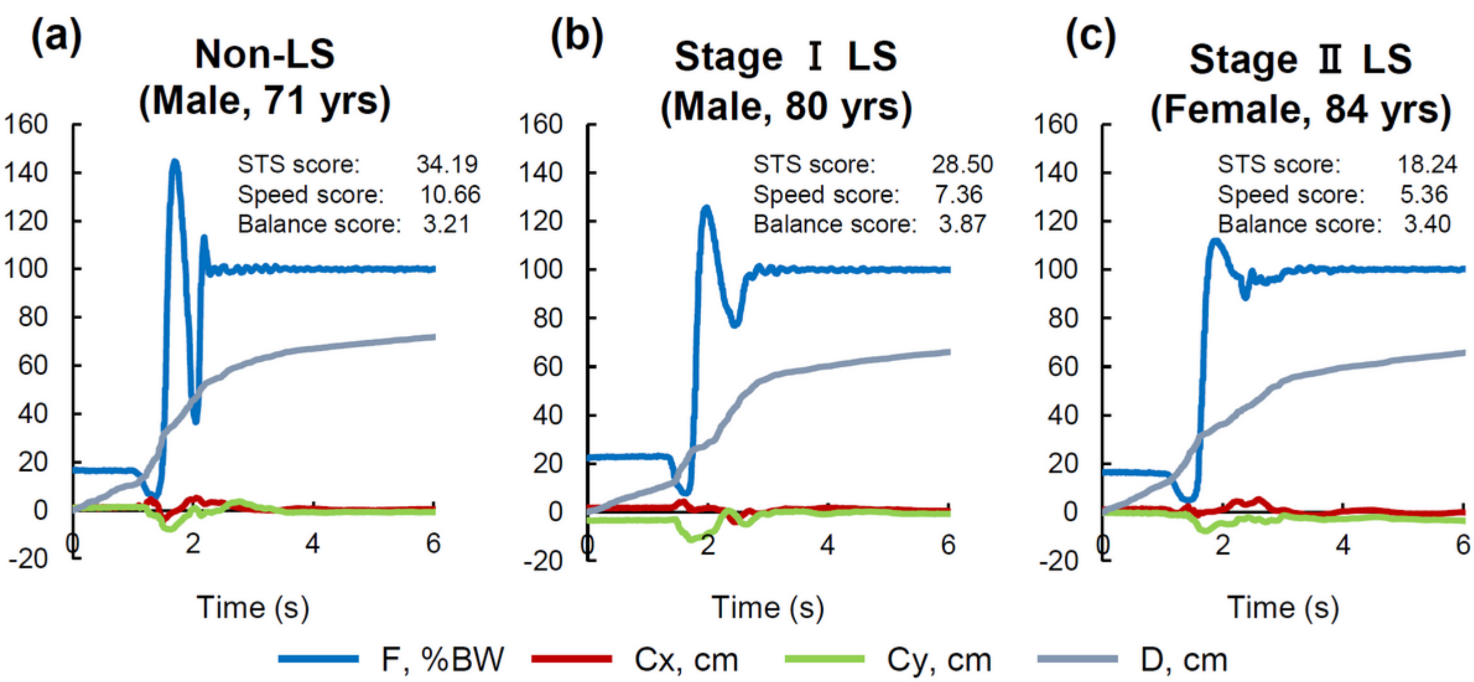

Figure 3

Typical graph patterns of the vertical ground reaction force and total center of pressure (COP) for each locomotive syndrome stage. F, vertical ground reaction force; Cx and Cy, COP trajectories in the Wii Balance Board; D, trajectory distance.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- AppendixA.docx