

Automatic Evaluation of the 30-s Chair Stand Test Using Inertial/Magnetic-Based Technology in an Older Prefrail Population

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Abstract—The aim of this study was to evaluate the inertial measures of the 30-s chair stand test using modern body-fixed motion sensors. Polynomial data fitting was used to correct the drift effect in the position estimation. Thereafter, the three most important test cycles phases (“impulse,” “stand up,” and “sit down”) were characterized and automatically analyzed. Automated test control is provided, making it possible for researchers without engineering knowledge to run the test. A collection of meaningful data based on kinematic variables is selected for further research. The proposed methodology for data analysis is a feasible tool for use in clinical settings. This method may not only improve rehabilitation therapies but also identify people at risk for falls more accurately than simply evaluating the number of cycles.

Index Terms—Accelerometer, frailty, gyroscope, signal analysis, 30-s chair stand test.

I. INTRODUCTION

AGING is related to considerable loss in muscle strength, which affects the ability of older people to function independently and makes them more vulnerable to falls and frailty syndrome [1]–[3]. Rising from a chair is regarded as one of the most demanding tasks in our daily life [4], and it has been

accepted as a prerequisite for successful gait performance [5]. Indeed, the 30-s chair stand test has been tested as a useful assessment tool for predicting falls [6] and to measure lower body strength in older adults [7]. This procedure also has high test–retest reliability, an ICC of 0.84 for men and an ICC of 0.92 for women [8], [9]. For example, a sensitivity of 88% has been found in [6] for the 30-s CST related to the history of falls. Similar correlations have been found in the ability to toilet independently in facility-dwelling elderly patients and in gait in people who have suffered a cerebrovascular accident [9]. While the 30-s chair stand test is in wide usage, only the total number of visually counted full stands is used as a clinical predictor index.

The sit-to-stand or stand-to-sit movements have already been studied separately and without the repetition effect, and different kinematic and kinetic parameters have been described. Duration is one of the most straightforward parameters to characterize both postural transitions [10], [11]. Nevertheless, other studies have suggested other parameters that could be of special interest in studying these transitions; specifically, these parameters could distinguish performance between different kinds of subjects. Therefore, maximum trunk, ankle, or head flexion has been assessed while subjects rise to standing from sitting [12]. By contrast, ground reaction forces [5] have also been measured to characterize both movements. Moreover, velocity peaks while standing up or sitting down [13], hip flexion, lower extremity joint angles, and the displacement of the center of mass [14] have been calculated as predictor variables related to Alzheimer’s disease. The trunk is important in generating the momentum that carries the body during the dynamic transition of standing up [15], and changes in the management of the trunk movements have been investigated as an early indicator of aging [16]. Overall, these studies confirm that both stand-to-sit and sit-to-stand transitions are complex enough to be evaluated in more detail. Furthermore, their kinematic variables may explain the motor control and performance involved.

Modern body-fixed motion sensors based on accelerometers and gyroscopes are powerful tools for sports studies and as clinical instruments to assess functional capacity [3], [17]–[19]. These types of measurements have been performed commonly in laboratories, using expensive and complex tools such as camera motion analysis systems and/or force plates. Lately, authors have started to take advantage of inertial units (IU) as a useful tool to measure kinematics from sit-to-stand and stand-to-sit transitions [20]. Durations were widely assessed [21]–[23] and

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stated as a useful indicator of actual physical ability in a community setting [24]. Moreover, other features such as balance [25] and power [26] were also obtained from the IU's outputs. However, the previously mentioned studies were focused on one single transition whereas our interest lies in the dynamic capability required for a more demanding task of performing a set of them consecutively. Moreover, this repetition approach allows the assessment of other features such as fatigue. Therefore, the first aim of this study was to evaluate the 30-s test from this inertial measures' point of view with a cheaper and portable tool. The second goal was to characterize and automatically analyze the three most important phases of the 30-s chair stand test cycles ("impulse," "stand up," and "sit down").

We hypothesized that this new clinical method to examine the 30-s test performance could yield meaningful variables to evaluate motor control, stability, and muscle power.

II. MATERIALS AND METHODS

A. Subjects

Twenty-six older subjects (14 males and 12 females M (SD) 83.16 (4.32) years, 74.26 (10.78) kg, 1.51 (0.73) m) volunteered to participate in this study. These subjects were chosen from the baseline data of the Toledo study for healthy aging (TSHA), a Spanish longitudinal population-based cohort aimed at studying the determinants of frailty in older adults. The study methods have been reported elsewhere [27]. The selected ones were all prefrail subjects according to the criterion described by Fried and coworkers [28]. Frailty was determined by the presence of three or more of the following components: slowness, weakness, weight loss, exhaustion, and low physical activity. Otherwise, subjects were classified as nonfrail if no component were present, and as prefrail if they had one or two of them. The components' definition has been described elsewhere [27]. Briefly, weight loss was defined as a unintentional loss of at least 4.5 kg during the last year; slowness was defined using the 3-m walking speed test, adjusted for sex and height according to the standards of the short physical performance battery [29]. To assess weakness, strength was measured with a Jaymar hydraulic dynamometer, according to the standards of the Hispanic EPESE [30]. Exhaustion was assessed using two questions ("I felt that anything I did was a big effort" and "I felt that I could not keep on doing things" at least 3 to 4 days a week") of the Center for Epidemiological Studies Depression Scale [31]. Finally, low physical activity was defined as the lowest quintile in the PASE scores [32].

All subjects completed a survey and a follow-up interview with a research team member. Then they were thoroughly informed about the experimental procedure, the purpose, nature, and possible risks associated with the study, as well as their right to finish their participation at their will. Their health history was also regarded to exclude those subjects who would not be able to perform the test properly due to poor health. All study participants gave a signed informed consent. If a participant was not able to consent, his/her caregiver (member of his/her family or legal tutor) consented on his/her behalf. The study protocol was approved by the Clinical Research Ethics Committee of the

Hospital Complex of Toledo, the Institutional Review Committee of the Public University of Navarra, and the Department of Health Sciences of the Government of Navarra, according to the Declaration of Helsinki.

B. Testing Procedures

The 30-s chair stand test was initially developed to assess lower body strength and evaluate functional performance and disabilities in the elderly population [7]. This test consists in standing up and sitting down from a chair with arms crossed across the chest as many times as possible within 30 s. Every subject performs the test as required and the mean number of completed cycles for this group was 12. All trials were performed in a hospital environment with the same chair and ambiance conditions.

C. Instrumentation

An inertial orientation tracker MTx (3 degree-of-freedom (DOF) human orientation tracker, Xsens Technologies B.V. Enschede, the Netherlands) attached over the L3 region of the subject's lumbar spine provided the kinematic data recorded in each trial at a sampling rate of 100 Hz. MTx combines itself nine individual MEMS sensors to provide drift-free 3-D orientation as well as other kinematic data: 3-D acceleration, 3-D rate of turn (rate gyro), and 3-D earth's magnetic field. Moreover, its fusion data algorithm based on the Xsens Kalman filter for 3 DOF computes statistically optimal high-accuracy 3-D orientation estimates with no drift from the 3-D acceleration, rate of turn, and earth magnetic field sensors.

The IU provides linear acceleration and rate of turn in a sensor-fixed Cartesian reference frame (xyz). Before the beginning of the test, with the subject seated on the chair and his back in upright position, the sensor-fixed reference frame was aligned with an earth-fixed global reference frame (XYZ). Thereafter, the Z -axis was on the vertical pointing upward; the X -axis lied on the lateral direction and its Y -axis on the front-back direction. Orientation data consisted in Euler angles (in XYZ or roll-pitch-yaw order) defining the rotation that aligns the global axis to the sensor-fixed reference frame at each time instant. Linear acceleration in the global reference frame without the gravity component was obtained from the acceleration provided by the IU by applying a rotation defined by orientation data.

D. Signal Processing

1) *Sit-Stand-Sit Automatic Calculation*: The Z -position signal was used as reference to accurately cut the signals into full sit-stand-sit cycles and to evaluate each of them separately. However, although we only needed to integrate the Z -acceleration twice to obtain this reference signal, the resultant signal became unusable within several seconds due to the drift effect. Thereafter, a novel method was used here based on polynomial curve adjustment and also on splines approximation. Firstly, a fourth-level polynomial was employed to estimate the tendency line that tracks the error due to the gravity component vestige. Second, cubic splines made it possible to reconstruct the

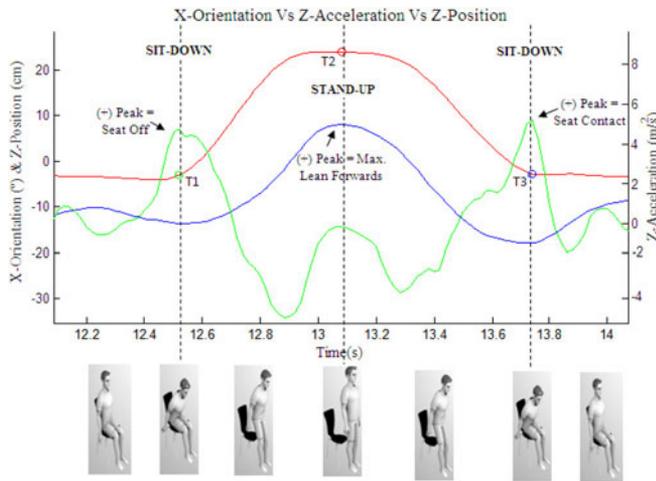


Fig. 1. X -orientation signal (blue line), Z -acceleration signal (green line), and Z -position signal (red line) from a signal sit–stand–sit cycle. The principal event markers are also included. The green, red, and blue bubbles show, respectively, T1, T2, and T3.

signal between outstanding points from the Z -position curves eliminating the inconstant MTx's bias. Finally, with both of them as a whole we were able to overcome the drift error constraint. Then, it was possible to obtain automatically the number of times that a subject performs the whole cycle without mistakes due to human observation.

2) *Sit–Stand–Sit Phase Determination*: Once the 30-s signals were cut into sit–stand–sit cycles, each individual cycle was divided into different movement phases. The first sit-to-stand transition was discharged from analysis since starting from a quiet sitting position influences the movement pattern. Therefore, it was not taken into consideration for the definition of the movement phases and the computation of the corresponding kinematic parameters. Three relevant phases according to different performance goals (“impulse,” “stand up,” and “sit down”) were identified for each stand–sit–stand cycle. During the impulse phase, the subject accommodates its weight to the chair and obtains the necessary push to leave the chair again and reach the upright position. The stand-up phase starts when the subject leaves the seat and finishes when he completely stands up. And, finally, the sit-down phase comprises the movement needed to reach the chair from the previous upright position. Throughout the text, the boundaries between the impulse/stand-up, stand-up/sit-down, and sit-down/impulse phases will be referred to as T1, T2, and T3, respectively (see Fig. 1). The events that define the phases' boundaries were detected from distinct marks in the Z -acceleration and X -orientation signals and so they were analyzed to assess the test performance.

All local maxima and minima of the X -orientation signal as well as the Z -acceleration outstanding positive peaks were obtained. A threshold for the peak-to-peak level was established to eliminate local extrema caused by signal noise instead of relevant angular displacements.

Consecutive orientation extrema differing in less than two degrees were discarded. Similarly, outstanding Z -acceleration peaks were obtained to establish the up-and-down transitions'

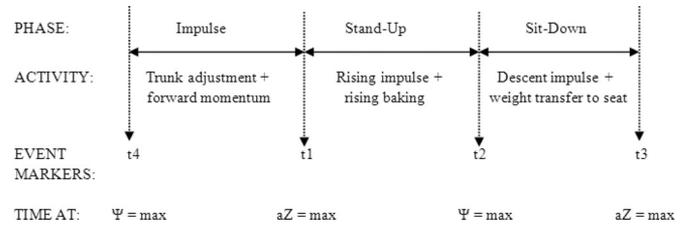


Fig. 2. Sit–stand–sit cycle diagram with phases, activities, and event marker definitions. Here, “aZ” refers to the Z -acceleration and “ ψ ” to the roll angle.

limits. For every cycle, the Z -velocity signal was used to distinguish the acceleration peak for the stand-up transition (subject moving upward—positive Z -velocity) from the sit-down related acceleration peak (subject moving downward—negative Z -velocity). All that information was combined to define the boundaries between the three relevant phases: impulse, stand up, and sit down (see Fig. 2).

The beginning of the cycle was set at the time when the subject reaches the seat after the previous sit to stand and a Z -acceleration peak is produced. During this phase, the subjects' weight is transferred from the legs to the seat and there is a trunk and balance adjustment. Next, the subject leans the trunk forward to take the necessary impulse to raise up, hence this phase's name “impulse phase.” In some cases, a pointed backward lean (X -orientation positive peak) which allows us to distinguish two subphases (the trunk and balance adjustment and the standing up impulse taking) was observed. However, in this study they were not taken into consideration as we focus on the basic movements of the sit–stand–sit cycle.

Next, the standing-up movement was performed during the “stand-up phase.” The start time (T1 event) was signaled by an abrupt positive change of vertical position and a Z -acceleration positive peak, which means that the subject has started leaving the chair, the “seat-off” event. During this phase, the vertical acceleration was converted to deceleration while the upward movement of the body mass was in progress. The vertical upward movement ended when the subject reaches the upright position. Just at that moment, there was a maximum backward trunk inclination that compensates the stand-up impulse (T2 event).

Finally, the cycle ended with the “sit-down phase” during which the subject changes its posture from erect standing to sitting down. As all movements occurred consecutively, the sitting down started just after the subject finishes the stand-up phase (T2 event). During this phase, negative Z -acceleration values reflect the impulse taken to initiate the downward movement, and then positive Z -acceleration was produced when the subject tried to slow down before reaching the chair. The descent finished when the seat contact was produced (T3 event), signaled by a characteristic positive peak in the Z -acceleration signal.

Once the different phases have been identified, linear acceleration, linear velocity, orientation, and angular velocity were evaluated to obtain relevant parameters at each phase. Kinematic parameters such as the phases' duration or the maximum acceleration in each phase were automatically computed (see Fig. 3). However, this paper only presents those parameters that

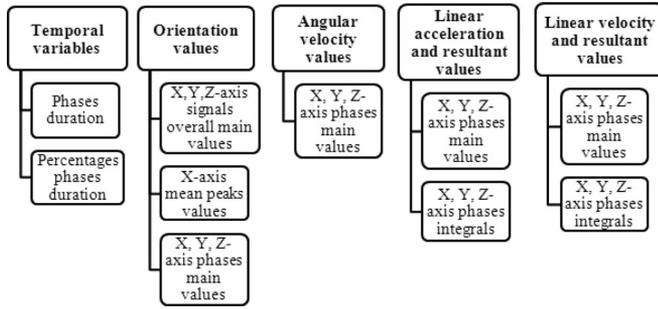


Fig. 3. Classification diagram for the obtained variables according to the signal they are obtained from.

TABLE I
PRINCIPAL VARIABLE VALUES

X-axis Orientation (°)	Impulse phase	Stand-up phase	Sit-down phase
Max. Pos. Var.	2.88 (4.10)	16.94 (3.65)	16.94 (3.65)
Max. Neg. Var.	11.99 (2.98)	9.92 (3.16)	14.37 (2.95)
Range	14.25 (4.44)	26.97 (3.92)	31.38 (3.90)
Mean	-3.08 (3.06)	2.04 (2.90)	-0.36 (3.20)
SD	4.76 (1.41)	9.86 (1.47)	11.71 (1.55)
X-axis Vang (rad/s)	Impulse phase	Stand-up phase	Sit-down phase
Peak Max.	0.46 (0.07)	0.32 (0.09)	0.34 (0.08)
Mean (SD)	0.08 (0.28)	-0.03 (0.16)	-0.05 (0.17)
Z-axis Acc. (m/s ²)	Impulse phase	Stand-up phase	Sit-down phase
Mean (SD)	0.94 (1.96)	0.44 (2.35)	0.20 (2.06)
AUC ^T _{acc}	0.97 (0.15)	1.76 (0.15)	1.49 (0.15)
AUC ⁺ _{acc}	0.88 (0.11)	0.91 (0.10)	0.69 (0.06)
AUC ⁻ _{acc}	0.09 (0.06)	0.85 (0.06)	0.81 (0.11)
ResAcc. (m/s ²)	Impulse phase	Stand-up phase	Sit-down phase
Mean (SD)	2.81 (1.28)	2.85 (1.24)	2.49 (1.15)
PeakMax	6.41 (1.44)	5.26 (0.63)	6.03 (1.40)
AUC ^T _{ResAcc}	2.01 (0.32)	1.59 (0.20)	2.09 (0.24)
Z-axis Vlin. (m/s)	Impulse phase	Stand-up phase	Sit-down phase
Mean (SD)	0.01 (0.12)	0.41 (0.31)	-0.39 (0.25)
Peak _{Max}	0.33 (0.11)	0.81 (0.05)	0.70 (0.05)
Tot. AUC ^T _{Vlin}	0.15 (0.03)	0.22 (0.03)	0.31 (0.02)
Pos. AUC ⁺ _{Vlin}	0.13 (0.03)	0.20 (0.03)	0.01 (0.01)
Neg. AUC ⁻ _{Vlin}	0.02 (0.01)	0.02 (0.01)	0.30 (0.02)
ResVlin. (m/s)	Impulse phase	Stand-up phase	Sit-down phase
Mean (SD)	0.45 (0.22)	0.52 (0.26)	0.50 (0.25)
Peak _{Max}	0.76 (0.09)	0.84 (0.06)	0.80 (0.07)
Tot. AUC ^T _{ResVlin}	0.39 (0.08)	0.28 (0.04)	0.43 (0.04)

There are the next acronyms within the table: ‘Vang.’= angular velocity, ‘ResAcc.’= resultant acceleration, ‘Max’= maximum, ‘Min’=minimum, ‘Var.’= variation, ‘Acc.’= acceleration, ‘ResAcc.’ = resultant acceleration, ‘Tot.’= total, ‘Pos.’=positive, ‘Neg.’=negative, ‘Vlin.’ = linear velocity, ‘ResVlin’=resultant linear velocity.

are envisaged to be more related to movement performance such as seen in Table I. The AUC_{acc} parameter was defined as the acceleration’s area under the curve related to the movement duration. This parameter expresses the sum of the acceleration amplitudes in order to take into account not only amplitudes but also time length. This is tantamount to the increase in velocity between the summation time limits. According to the displacement’s direction, the AUC_{acc} is composed of a positive component (AUC⁺_{acc}, with the movement’s direction) and a negative

one (AUC⁻_{acc}, with the opposite direction). The first parameter evaluates the necessary impulse to carry out each transition (movement acceleration), while the second one is related to the transition control since the first impulse must be compensated to reach the stand-up or the sit-down position (movement deceleration). These are interesting parameters since they have been related to the extremities strength to perform a movement and so to the functional ability [33]–[35].

3) *Statistical Analysis*: The standard statistical methods were used to obtain the mean (M) and standard deviation (SD) of each phase parameter across cycles and subjects. The differences between the predefined movement phases (impulse, stand up, and sit down) were determined using one-way analysis of variance (ANOVA), with Newman–Keuls *post hoc* comparisons. When normality test failed ($P < 0.05$), the Mann–Whitney rank sum test was employed. The $p < 0.05$ criterion was used for establishing statistical significance. Box plots of each parameter for the different movement phases are used to graphically display the variable’s location. The box itself contains the middle 50% of the data, the upper and lower edges of the box indicate the 75th and the 25th percentile, and the central line is the median value of the data. The ends of the vertical lines or “whiskers” are the minimum and maximum data values whereas points outside whiskers’ ends represent outliers or suspected ones.

III. RESULTS

A. Temporal and Kinematic Parameters

1) *Phase’s Times*: The duration M (SD) of an impulse phase was similar (0.71 (0.13) s) to those observed in the corresponding stand-up and sit-down phases (0.74 (0.06) s and 0.80 (0.10) s, respectively).

2) *Orientations*: The average roll angle range of the 30-s chair test (46.88 (11.16)°) was greater ($p < 0.01$) than that of pitch yaw angles (14.50 (8.15)° and 18.83 (7.15)°, respectively). The roll angle ranges during the impulse, stand-up, and sit-down phases were of (14.25 (4.44)°, 26.97 (3.92)°, and 31.38 (3.90)°, respectively).

3) *Angular Velocity*: The maximum angular velocity in the X-axis was greater at the impulse phase (0.46 (0.07) °/s) than those recorded during the stand-up (0.32 (0.09) °/s) and sit-down phases (0.34 (0.08) °/s) ($p < 0.01$) (see Table I).

4) *Linear Velocity*: The maximum linear velocity in the Z-axis in the stand-up phase (0.81 (0.05) m·s⁻¹) was greater ($p < 0.01$) than that obtained in the sit-down phase (0.70 (0.05) m·s⁻¹) (see Table I).

5) *Linear Acceleration*: The maximum positive and negative accelerations in the z-axis were similar during the stand-up (3.73 (0.46) m·s⁻² and 4.15 (0.61) m·s⁻²) and sit-down phases (3.36 (0.53) m·s⁻² and 4.70 (1.15) m·s⁻²) ($p > 0.01$). AUC_{acc} during the stand-up phase was significantly greater ($p < 0.01$) (1.76 (0.15) m·s⁻¹) than that observed during the sit-down one (1.49 (0.15) m·s⁻¹). Although the AUC⁻_{acc} part is similar for both transitions (0.85 (0.06) m·s⁻¹ stand up, and 0.81 (0.11) m·s⁻¹ sit down), the AUC⁺_{acc} one is greater for the stand-up transition (0.91 (0.10) m·s⁻¹) than for the sit-down one (0.69 (0.06) m·s⁻¹).

IV. DISCUSSION

The 30-s chair stand test is regarded as a good indicator of lower limb strength [7], [36], but the only quantitative result currently obtained is the number of full cycles counted by the tester. A unique outcome of this study was the description of an automated procedure for a detailed analysis of the 30-s chair stand test, based on the processing of the signals provided by an IU. The proposed automatic procedure eliminates the inaccuracy that results from human supervision. This study also enables the definition of meaningful kinematic variables that indicate movement performance and may be related to functional activity indicators, especially in elderly patients who are more liable to experience muscle strength loss and frailty syndrome.

The sit-to-stand movement has been thoroughly studied in the literature [14], [21], [22], [25], [26], [35], [37]–[41]. The stand-to-sit transition, however, has received much less attention [4], [5], [10], [11], [13], despite being of paramount importance in the elderly. Tests that involve continuous repetition, such as the 30-s chair stand test, had not yet been evaluated with body-fixed inertial sensors. To our knowledge, this is the first study describing a method to extract multiparametric kinematic measures in order to analyze both transitions during a 30-s test. As a result, mean values were obtained to characterize an individual's performance of a given movement. Additionally, a new impulse phase was defined which links the last sit down to the next stand up. However, comparison of these results with those of single-transition studies must be performed cautiously because different initial conditions clearly influence the performance of a movement. In this study, the subject does not begin the movement from an initial resting state. To perform the sit-to-stand transition, the subject must first compensate for the sit-down impulse and gather enough momentum to stand up. After sitting down, subjects do not get any rest time before initiating the next transition.

In the literature, postural transitions are most often characterized by their duration [10], [21], [23], [26] or by the trunk range of motion [16]. Although not assessed here, balance derived parameters [25] and power [26] had been also studied in the literature. Duration was commonly obtained by using the angular velocity [22], the integration of the orientation signal [42], or the derivative of the transversal acceleration. However, this study used the vertical acceleration to determine when the subject left or reached the chair [38]. Moreover, most papers compare the performance of elderly and young populations [43] or determine descriptive parameters for the standing and sitting movements [4]. In this study, we followed the latter approach, describing the transitions involved in the 30-s chair stand test for a group of prefrail elderly people. Nevertheless, the same parameters could be analyzed to compare different populations.

Regarding specific time values, published studies of single sit-to-stand transitions have reported movement durations ranging from 1.2 to 5.9 s. In these reports, 2 s was the most frequently observed duration [41]. However, in our study, the mean length of the sit-down phase is 0.80 s. This noticeable decrease may be explained by the fact that subjects are encouraged to complete as many cycles as possible and by the difference in initial

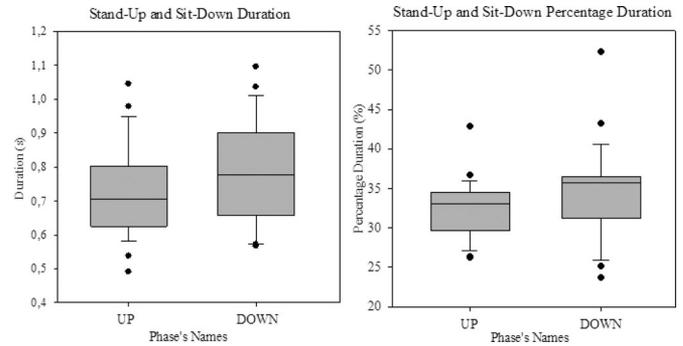


Fig. 4. Box plots for the time invested during the stand-up and sit-down phases, left, and for the time percentage inverted during the stand-up and sit-down phases, right.

conditions (described previously). Because the time spent performing a specific activity is a simple but important indicator of the subjects' functional capabilities [44], transition duration has also been regarded as an indicator of fall risk [37], [42]. For instance, a significant increase in the mean and standard deviation of transition duration has been reported when comparing a high and low fall-risk group [11]. When comparing stroke patients to healthy subjects, it is generally the case that the stroke victims spend more time performing standing-up and sitting-down transitions (separately evaluated) [44]–[46]. Furthermore, stroke fallers tend to spend more time performing the sit-to-stand task than nonfallers do [37].

The duration comparison between the three defined phases (i.e., impulse, stand up, and sit down) showed no significant differences. Interestingly, when normalized to the total cycle duration, significant differences arise between the percentage of time corresponding to the sit-to-stand and stand-to-sit transitions (see Fig. 4). In this study, the prefrail older group examined tends to allocate a larger part of the total cycle time to descending 34.6% rather than to rising 32.3%. This is in agreement with the results of single-transition studies [5], [43]. This result reinforces the idea that elderly populations tend to perform the sitting-down transition more slowly and with more caution than the standing-up one. This difference may be due to the different center of mass location adjustment or to the lack of visual information regarding the location of the endpoint (seat) [5]. Additionally, when considering the number of times that the subjects performed full cycles of standing up and sitting down, we observed a tendency to invest more time for each individual sitting phase when the number of repetitions is smaller. The slower movements may be a function of the decreased ability to generate power in this population [4].

As expected, the greatest range of motion was found in the sagittal plane (rotation around the X -axis, 46.88°) when compared to the range of motion around the Y - and Z -axes (14.50° and 18.83° , respectively). The X -axis orientation signal shows a characteristic pattern with four distinct local extrema that correspond to different movement tasks. At the beginning of the cycle, a maximum in the X -axis orientation is registered; this maximum corresponds to a backward lean immediately following contact with the seat (as the body is accommodated by the

chair). The subsequent minimum reflects a forward inclination of the trunk that gives the subject enough impulse to rise up. Next, a maximum is observed when the subject reaches the standing position and leans the trunk backward. Finally, a last minimum in the X -axis orientation indicates the forward inclination of the trunk needed to reach the chair during the sit-down movement.

During the rising up and descent phases, no significant differences were observed in the angular displacements for the X -axis orientation. This result is in agreement with the findings of Mourey *et al.* [43] who reported no differences in angular displacement during the standing-up and sitting-down transitions (evaluated separately). The maximum x -axis angular value recorded during the impulse phase seems to be another meaningful parameter for the task of movement procedure assessment. This parameter indicates how the subjects manage his/her body movements when standing up. However, further studies are required to determine the utility of these and other parameters in distinguishing different populations. Acceleration values were related to the forces employed to perform the required sit-to-stand cycle. Attempts have been made to identify a variable that would allow the 30-s chair test to evaluate the lower extremities strength [35]. Peak values from the different phases may give an idea about the muscular power required to perform both the standing-up and the sitting-down transitions. In this study, absolute values were recorded, but positive and negative peaks were distinguished according to the movement's direction. Thereafter, positive values were those that were in the same direction as the performed movement, while the negative ones were those in the opposite direction. During the standing-up and sitting-down phases, no significant differences were found for the positive and negative peaks. This means that this population tends to invest similar forces for both starting and compensating the impulse needed to execute the stand-up and sit-down transitions.

Movement's impulses are related to muscular power management and may be an indicator about the subject's state of health [34], [47], [48]. In this study, acceleration related to the sit-to-stand transition was assessed according to the AUC_{acc} parameter, which indicates the area under the curve of the acceleration signal of each transition or, what is the same, the impulse that a subject executes to completely perform both the stand-up transition and the sit-down transition. Moreover, not only the net parameter but also the AUC_{acc}^+ (impulse needed to start the movement) and AUC_{acc}^- (impulse needed to compensate for the initial one) components were obtained. Here, significant differences were found for the positive (in the same direction as the movement), but not for the negative parameter (in the opposite direction of the movement). There are also differences in the net value of AUC_{acc} (i.e., the sum of the negative and positive components) when comparing the standing-up and sitting-down phases (see Fig. 5). As with the maximum and minimum peaks, different values were observed between the AUC_{acc} part for the impulse with the same direction as the performed movement, AUC_{acc}^+ , and another part with the opposite direction, AUC_{acc}^- . These subjects generated different AUC_{acc} values when standing up or sitting down, which indicates that these two tasks

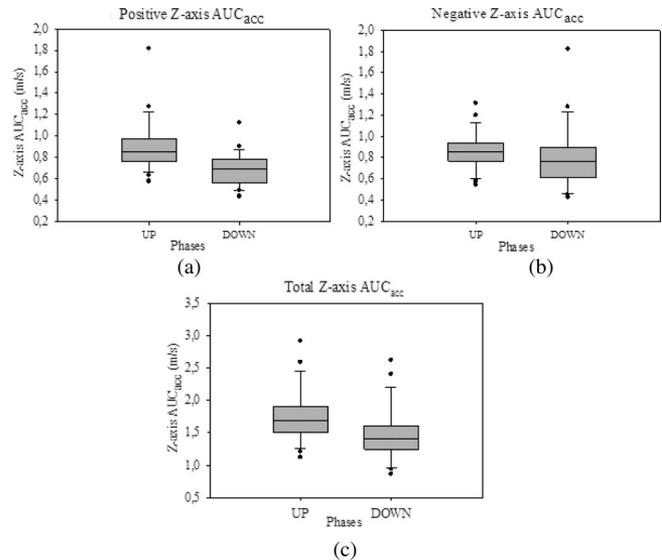


Fig. 5. (a) Positive, (b) negative, and (c) total Z -axis AUC_{acc} box plots for the stand-up and sit-down phases.

were performed in different ways. AUC_{acc}^+ values represent the forces that the subject exerted to reach the upright position or to reach the chair while AUC_{acc}^- values are those required to counteract the previous ones. This population generally invests more positive force during the sitting-down process. This result is logical because prefrail subjects tend to let themselves fall down into a seat rather than controlling their descent. Thereafter, high positive forces while sitting means that the subject takes advantage to the gravity force to descent instead of doing the effort to have power over it. However, the similarity to the AUC_{acc}^- values indicates that these individuals tend to control in a similar way both transitions. When comparing the net AUC_{acc} values, differences indicate that subjects from this population tend to need more force to stand up than to sit down. This result reinforces the notion that uncontrolled sit downs occurred, especially in older frail populations.

A limitation of this study, from the scientific research point of view, was the use of a single sensor attached to the body's center of mass (over the L3 region of the lumbar spine). As an alternative several matchbox-sized sensor nodes could be attached to different trunk locations to obtain better information about the trunk displacements [26]. An optoelectronic tracking system could also be used [49]. Similar sensors could be located on other body parts such as the knee [12] to evaluate the test. Then, further information could be gathered to evaluate the role of other body parts during the sit-stand-sit test.

V. CONCLUSION

In summary, this study provides a unique approach to analyze the 30-s chair stand test and suggests that body-fixed sensors are a powerful tool for this analysis. Two important improvements have been introduced. First, this method allows for automated control of the test. This automation makes it possible for researchers without any engineering knowledge to run this test. Furthermore, this method avoided the human errors that occur

during testing. Second, this method also allowed the collection of meaningful data based on kinematic variables throughout the performance of transitions. This ability may be of special interest when discriminating among healthy, prefrail, and frail subjects.

These results demonstrate that accelerometry can complement the currently utilized test outcome of the 30-s test, namely, the number of cycles performed. The kinematic values obtained provided information about the motion's quality and an evaluation of how the movements were carried out. The proposed methodology for data analysis is a feasible tool for use in clinical settings. This method may not only improve rehabilitation therapies but also identify people at risk for falls more accurately than simply evaluating the number of cycles.

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Authors' photographs and biographies not available at the time of publication.