Instrumented 30-s Chair Stand Test: evaluation of an exercise program in frail nonagenarians

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Abstract. Performance test such as the 30-second chair stand one (30-s CST) are a cornerstone for detecting early declines in functional independence. However, only the total number of visually counted full stands is normally used as a clinical predictor. Recent researches in body-fixed sensors field highlight their ability to accurately evaluate movement performance based on kinematic parameters. The instrumented version of the 30-s CST has revealed an interesting tool to frailty detection using this information [17,12,14]. The effect of a multicomponent training on a randomized controlled trial with twenty frail nonagenarians (91.9±4.1 years old) are evaluated here based on the instrumented 30-s CST. It was observed that significantly higher number of cycles was performed by the intervention group but the majority of the kinematic parameters from both groups did not significantly change in mean before and after the exercise-period. However, the RMS value of the Y-orientation ($p=0.028$) as well as the so-called fatigue index [13], through the performed cycles, decreased significantly in the exercised group after the intervention ($p=0.028$ and $p=0.034$ respectively). Other parameters such as information about the movement smoothness could also be interesting to detect subtle functional changes [10].

Keywords: 30-s chair stand test, inertial units, exercise-program effect, kinematic parameters.

1 Introduction

The ageing trend is becoming a major concern in our society. At present, population is constantly increasing and, in fact, the age group which is most rapidly growing is the one over the age of ninety [2]. This relatively recent explosion of large numbers of very old people living in our communities has brought to light critically important healthy problems (i.e. co-morbidities, frailty, fall-risk) [20]. Indeed, as people are living longer and getting older, the chances of dependency on medical, welfare and other services will be greater, soaring health-care cost. Many studies highlight that exercise is the key to healthy aging [5,6,22]. Those people who practice regular exercise are able to boost energy, maintain their independency, manage symptoms of aging, and, as a result, achieve a better health-status their last years of life [4]. However, it is important to choose the right assessment tools to first know the patients physical state and then design an effective exercise program [16].

Up until now, the clinic test used to assess function have been based on basic parameters (i.e. time-durations, number of cycles), and, in some cases, they are balanced by the ability and experience of the tester. Therefore, it is needed to improve the mentioned test and furnish clinicians with new automatic tools able to provide objective measures of the movement performance. Body-fixed sensors are envisaged as a promising device to this aim [3,11,18]. These relatively cheap, small and portable systems are able to accurately and automatically evaluate movement performance based on objective kinematic parameters [1,7,10,15].

Here, we want to assess the utility of this new device to evaluate the effects of a training program in elderly population. To this aim, the instrumented version of the 30-s CST has been employed since it was previously tested its ability to differentiate between different frailty levels [17]. Kinematic parameters selected from previous studies were evaluated in terms of mean values of the different phases of each performed cycle (i.e. impulse, stand-up and sit-down). Moreover, additional parameters were obtained to test if they are able to provide meaningful information about the treatment effect (i.e. "fatigue-index" (FI), RMS values). Comparison was done with those authors that have obtained similar measures to detect subtle differences after the exercise intervention.

2 Materials and methods

2.1 Subjects

Participants were institutionalized oldest old patients from the Pamplona (Spain) area and the restrictions to be included into the study were: (1) be 85 years or older, (2) met the Fried's criteria for frailty. According to this definition, frailty is determined by the presence of three or more of the following components: slowness, weakness, weight loss, exhaustion, and low physical activity [8]. The exclusion criteria were the absence of frailty or pre-frail syndrome and the presence of dementia, disability (defined as a Barthel Index (BI) lower than 60 as well as inability to walk independently without external help), recent cardiac arrest, unstable coronary syndrome, active cardiac failure, cardiac block or any unstable medical condition. Fig. 1 shows the participants flow diagram. Before the study, each participant underwent a medical assessment to check the criteria. Then, the subjects were randomized into two groups: an exercise group (EG), aged 93.4±3.2, and a control group (CG), aged 91.1±1.1. This procedure was established according to the "CONSORT" statement, which can be found at http://www.consort-statement.org/. The study was conducted according to the Declaration of Helsinki, and the protocol was approved by the local Institution Review Broad.

The EG underwent a twice-weekly, 12-week multi-component exercise program with a minimum of 2 days elapsed between consecutive training sessions. Before the exercise intervention, the participants were carefully familiarized with the training procedures and a specific warm-up was performed before each session. The 40-min sessions were composed of muscle power resistance training combined with balance and gait retraining as well as functional tests. The resistance exercises were focused on the major upper and lower limb muscles and loads were progressively increased to optimize the muscle output in this population (8-10 repetitions, 40-60% of the one-repetition maximum). Balance and gait retraining exercises (i.e. semi-tandem foot standing, line walking, etc.) progressed in difficulty and also functional exercises, such as rises from a chair, were performed. All training sessions were carefully supervised by one experienced physical trainer. The CG only performed exercises routinely encouraged in most Spanish nursing homes, such as small active and passive movements to improve upper and lower mobility.

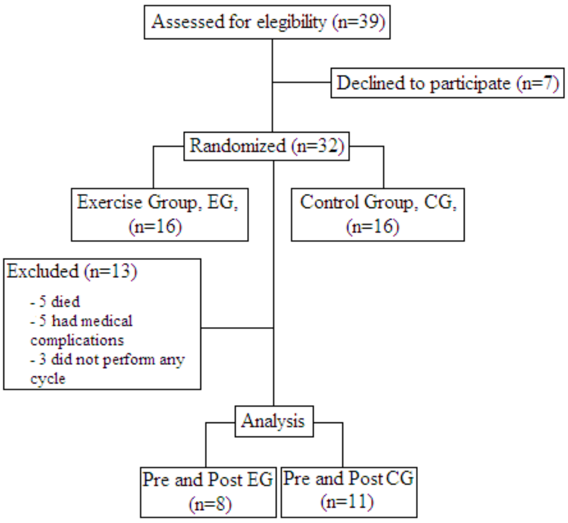

Fig. 1. Flowchart for screening, recruitment, randomized intervention and analysis.

2.2 Testing procedures

The 30-s CST was carried out in institutionalized frail nonagenarians to assess the ability of this test to detect exercise intervention effects. This test consists of standing up and sitting down from a chair as many times as possible within 30 seconds. A standard chair (with a seat height of 40 cm) without a backrest but with armrests was used. Prior to data collection, participants took part in a familiarization procedure. Initially, subjects were seated on the chair with their back in an upright position. They were instructed to look straight forward and to rise after the “1, 2, 3, go” command at their own preferred speed with their arms folded across their chest. All trials were performed using the same chair and with similar ambient conditions and at approximately the same time of the day throughout the study. The same investigator, who was blinded to the training group of subjects, oversaw the test both before and after the intervention.

2.3 Instrumentation

An inertial MTx Orientation Tracker (WSENS, Xsens Technologies B.V., Enschede, Netherlands) was attached over the L3 region of the subject's lumbar spine to provide the kinematic data for each trial. It recorded at a sampling rate of 100 Hz. The L3 position was chosen because of its proximity to the body's center of mass (CoM) in the standing position. The nine individual MEMS sensors from the MTx provided kinematic data such as the 3D acceleration and the 3D rate of turn (rate gyro). Moreover, the drift-free 3D orientation was also supplied by the MTx using Kalman filters and the previously mentioned kinematic data.

2.4 Signal processing

An automated data analysis procedure was implemented using Matlab 7.11 (MathWorks Inc., Natick, MA, USA) to improve the objectivity and simplicity of the current 30-s CST evaluation taking advantage of the MTx data. Therefore, an accurate count of the number of repetitions was provided, removing failed attempts, as well as kinematic parameters obtained from the MTx data. The procedure was implemented as a three-step algorithm:

1. Z-velocity and Z-position signals were obtained after removing the drift generated by the double integration with the "PB-algorithm" [19].
2. The different sit-to-stand-to-sit cycles and their main phases (impulse, stand-up and sit-down) were defined within the 30-s test duration [18]. An automatic count of the performed cycles was provided. Moreover, each cycle was divided into the mentioned phases based on markers obtained from the Z-position, X-orientation and Z-acceleration data, Fig. 2.
3. Durations and temporal kinematic parameters were extracted from the MTx data. In particular, mean measures of each phase of the performed cycles were obtained for maximum and minimum peaks, ranges and mean values. Furthermore, other mean measures (i.e. maximum X-orientation ranges and modified impulses of the Z-acceleration) were also obtained for the different phases of the fulfilled cycles.

In this case, only the parameters that previously provided valuable information to detect frailty differences have been evaluated:

- Number of performed cycles.
- Duration: impulse, stand-up and sit-down phases as well as sit-stand-sit cycle.

- X-orientation: range and mean values of each phase (i.e. impulse, stand-up and sit-down).
- Z-acceleration: maximum, minimum, and mean values of each phase (i.e. impulse, stand-up and sit-down).
- “Modified-impulse” values for the stand-up and sit-down phases [18].

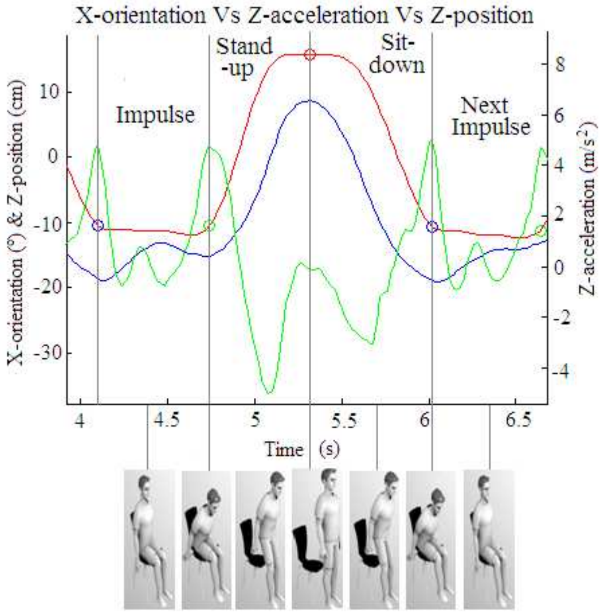

Fig. 2. Z-position (red-line), Z-acceleration (green-line) and X-orientation (blue-line) signals during a sit-stand-sit cycle from the 30-s CST

Additional parameters were also obtained using the previously described algorithm for the 30-s CST. Root mean square (RMS) measures of those directions of the acceleration and orientation data which are not involved into the movement performance were extracted, Equation 1. In particular, Y-orientation (pitch) and Z-orientation (yaw) as well as X-acceleration were selected as being abnormal movements for the sit-stand-sit task. Moreover, a fatigue index (FI) was calculated, based on [13], as the difference of average velocity and also of peak velocity for the different phases of each cycle, Equation 2.

$$RMS = \sqrt[2]{\frac{1}{N}\sum_{1}^{N} x[n]^2} \qquad (1)$$

$$FI = [mean(Zvelocity) - max.peak(Zvelocity)]_{30-s\ CST} \qquad (2)$$

2.5 Statistics

The above parameters were estimated for each subject, and their mean (M) and standard deviation (SD) values for each phase across performed cycles were calculated within each group. Differences in both groups (EG and CG), before and after the exercise-program, were assessed using the t-test due to the reduced number of participants. Statistical significance was set at $p < 0.05$. In the cases where the power of the performed test with alpha equal to 0.05 was below to 0.8, a non-parametrical test (i.e. Wilcoxon Signed Rank Test) was checked. 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. The Sigmaplot Software package (version 11.0) was used to analyze all data.

3 Results

3.1 Performed cycles

The number of performed cycles significantly improved after the intervention-period in the EG ($p=0.031$) while any difference was found in the CG ($p=0.676$).

3.2 Durations

EG patients tended to reduce the duration values of the cycles. However, any significant difference was found for both EG and CG before and after the intervention in any of the duration values evaluated in term of means for the fulfilled cycles.

3.3 Kinematic parameters

Only range and mean values of the X-orientation signal for the impulse phase showed a significant reduction for the EG ($p=0.05$ and $p<0.001$), while there was any significant change in the CG ($p=0.876$ and $p=0.694$). The rest of parameters related to the X-orientation signal (i.e. max., min. peaks of the different phases, maximum ranges of the stand-up and sit-down phases) presented no-changes before and after intervention in both EG and CG for the fulfilled cycles ($p>0.05$).

Related to the Z-acceleration signal, only the maximum and range value of the sit-down phase as well as the maximum value of the impulse phase presented a significant rising ($p=0.02$, $p=0.03$ and $p=0.034$) in the EG while the same values in the CG did not present any change. The rest of parameters derived from the Z-acceleration signal (i.e. "modified-impulses") presented no-changes in both EG and CG ($p>0.05$) for the fulfilled cycles ($p>0.05$).

Any of the parameters obtained from the Z-velocity signal differed before and after the intervention in both groups ($p>0.05$).

	Parameter	PrC[1] Mean (SD)	PtC[1] Mean (SD)	p-Value (PrC,PtC)	PrE[1] Mean (SD)	PtE[1] Mean (SD)	p-Value (PrE,PtE)
	Nb of cycles	5.8 (2.4)	6.4 (3.5)	0.898	7.0 (3.0)	10.0 (5.0)	0.031*[2]
Impulse	TD (s)	2.0 (1.7)	1.7 (1.6)	0.470	2.0 (1.6)	2.1 (3.8)	0.105
	X-Orient.[3] Range (°)	24.6 (9.6)	23.8 (13.8)	0.898	24.7 (9.7)	18.9 (17.4)	0.050*
	X-Orient. Mean (°)	-14.7 (17.8)	-14.6 (16.0)	0.694	-16.1 (22.6)	-22.6 (14.4)	<0.001*
	Z-Ac.[2] Max. (m/s)	8.5 (3.7)	9.2 (3.5)	0.520	5.9 (4.2)	11.8 (5.7)	0.034*
	Z-Ac. Min. (m/s)	-0.8 (0.9)	-2.1 (1.2)	0.520	-1.4 (1.6)	-1.3 (2.0)	0.313
	Z-Ac. Mean (m/s)	0.6 (0.3)	0.7 (0.4)	0.520	0.7 (0.5)	1.5 (1.9)	0.442
Stand-up	TD (s)	1.6 (0.7)	1.4 (0.8)	0.358	1.5 (0.6)	1.2 (0.8)	0.279
	X-Orient. Range (°)	33.0 (10.3)	33.1 (10.1)	1.000	30.5 (16.8)	28.4 (10.6)	0.798
	X-Orient. Mean (°)	-22.4 (17.3)	-21.6 (16.8)	0.948	-25.3 (20.5)	-25.6 (10.0)	0.945
	Z-Ac. Max. (m/s^2)	2.8 (0.9)	2.2 (0.6)	0.042*	3.0 (1.6)	3.1 (1.9)	0.844
	Z-Ac. Min. (m/s^2)	-2.1 (0.9)	-2.1 (0.7)	0.966	-1.9 (0.7)	-2.6 (1.1)	0.195
	Z-Ac. Mean (m/s^2)	-0.2 (0.1)	-0.3 (1.3)	0.032*	-0.2 (0.1)	-0.3 (0.2)	0.039*
	AUC^{T}_{ac}	1.0 (0.2)	0.9 (0.2)	0.700	1.0 (0.4)	1.0 (0.3)	0.919
	AUC^{+}_{ac}	0.4 (0.1)	0.3 (0.1)	0.465	0.4 (0.1)	0.4 (0.1)	0.748
	AUC^{-}_{ac}	0.6 (0.3)	0.6 (0.2)	0.700	0.6 (0.2)	0.6 (0.2)	0.950
	Z-Vel.[2] Max. (m/s)	0.5 (0.1)	0.4 (0.1)	0.320	0.4 (0.1)	0.5 (0.1)	0.383
	Z-Vel. Mean (m/s)	0.2 (0.1)	0.2 (0.1)	0.638	0.2 (0.1)	0.3 (0.1)	0.195
Sit-down	TD (s)	1.5 (0.4)	1.2 (0.3)	0.083	1.3 (0.4)	1.1 0.5)	0.313
	X-Orient. Range (°)	29.8 (9.3)	26.2 (8.0)	0.765	23.4 (4.5)	24.2 (4.1)	0.641
	X-Orient. Mean (°)	-20.9 (19.6)	-18.6 (16.8)	0.966	-22.2 (16.4)	-23.7 (8.9)	0.742
	Z-Ac. Max. (m/s^2)	8.2 (3.5)	9.2 (3.1)	0.577	5.4 (3.1)	10.8 (5.0)	0.02*
	Z-Ac. Min. (m/s^2)	-2.1 (0.6)	-2.3 (1.1)	0.966	-2.1 (0.5)	-2.3 (0.7)	0.547
	Z-Ac. Mean (m/s^2)	-0.3 (0.1)	-0.3 (0.1)	0.175	-0.3 (0.1)	-0.2 (0.1)	0.313
	AUC^{T}_{ac}	1.1 (0.3)	1.2 (0.4)	0.966	1.2 (0.3)	1.1 (0.2)	0.733
	AUC^{+}_{ac}	0.6 (0.2)	0.6 (0.2)	1.000	0.7 (0.2)	0.6 (0.2)	0.560
	AUC^{-}_{ac}	0.5 (0.2)	0.6 (0.3)	0.966	0.5 (0.1)	0.5 (0.1)	0.630
	Z-Vel. Min. (m/s)	-0.6 (0.1)	-0.6 (0.2)	0.638	-0.6 (0.1)	-0.6 (0.1)	0.641
	Z-Vel. Mean (m/s)	-0.2 (0.0)	-0.2 (0.1)	0.206	-0.2 (0.1)	-0.3 (0.1)	0.461
	Cycles TD (s)	5.1 (2.5)	4.3 (2.4)	0.237	4.8 (2.4)	4.4 (4.9)	0.130
	$RMS\|_{Y\text{-Orient.}}$	4.8 (2.1)	6.7 (3.9)	0.273	4.2 (2.3)	2.3 (0.8)	0.028*
	$RMS\|_{Z\text{-Orient}}$	10.1 (8.7)	6.1 (8.4)	0.521	7.3 (3.3)	7.3 (3.8)	0.844
	$RMS\|_{X\text{-Ac.}}$	0.4 (0.1)	0.4 (0.1)	1.000	0.4 (0.1)	0.4 (0.1)	0.959
	FI (m/s)	-12.3 (6.9)	-12.3 (0.985)	0.985	-8.1 (6.5)	-16.2 (7.3)	0.034*

Table 1.

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[1] PrC, PtC, PrE and PtE refer to the Pre-Control, Post-Control, Pre-Exercise and Post-Exercise groups, respectively.

[2] The symbol (*) means that there is a statistical significant difference

[3] Orient., Ac. and Vel. refer to orientation, acceleration and velocity, respectively.

3.4 Additional parameters

Dealing with the RMS values, only the Y-orientation signal presented a significant reduction (p=0.028) for the EG while the CG did not significantly differ before and after the exercise-intervention (p=0.273).

Parameter related with the fatigue-effect present positive results, there is a significant improvement in the EG after the intervention-period (p=0.034) while this difference was not found in the CG (p=0.985).

4 Discussion

This study is contributing to the field of activity monitoring presenting objective parameters able to improve clinical analysis. The aim is to characterize the 30-s CST in more detail, using a single IU, attached to the lower back. Recorded data (i.e. accelerometer and angular velocity) was used to estimate kinematic parameters in order to evaluate the effect of an exercise intervention. Parameters such as the ones tested in [17] to detect frailty levels and additional ones to characterize the signals along the test duration (i.e. RMS values and FI) were evaluated here to assess the dynamics of the body movement during the 30-s CST.

One of the important results of this study is that not all of the parameters that previously showed significant discriminating properties to distinguish between different frailty groups [10,17] were meaningful enough to detect minor improvements resulting from rehabilitation [10]. In fact, only the number of cycles, the X-orientation range and mean value during the impulse phase and the maximum peak of Z-acceleration of the sit-down transition were able to detect improvements in the EG while any difference was found in their counterparts. Subjects from the EG perform a significant higher number of cycles after the exercise program. Moreover, previous results reveal these subjects also tend to decrease the range of the X-orientation during the impulse phase, reflecting a more stable postural transition after the exercise program [10]. This result is also in accordance with the ones presented in [17] where a significant reduction of the X-orientation range during the impulse phase was observed for healthy subjects in comparison with pre-frail and frail counterparts. Although the rest of parameters did not present significant differences, they tend to improve after the exercise-period, likely reflecting improvement associated to the intervention program. These results confirm and extend previous results about time-domain kinematic features of the trunk during postural transitions [10,21]. However, other parameters presented in these previous studies, did not show significant differences here (i.e. transition duration reduction [9,21], and maximal velocity rising [21]). These differences may be due to the disparity in the employed test. While previous studies only assess one or three consecutive cycles of sit-stand-sit transitions at the most, our study was based on the 30-s CST where subjects perform as many transitions as possible during the test duration. Therefore, subjects tend to perform cycles in a similar kinematic manner in mean while they are able to carry on much more transitions at the end. This result shows that maybe other kind of metrics should be obtained from this test to evaluate subtle differences as mentioned in the subsequent paragraphs.

Another important result of this study is that other analysis based on the global pattern of those signals not directly involved on the movement directions could provide meaningful information. In this case the RMS value of the Y-orientation signal showed an important reduction in the EG after the intervention, Figure 3 (a). This means that these subjects did not perform medio-lateral movements to compensate imbalances during the test so that that they economize effort employed and are able to perform more cycles than before. Other similar parameters should be assessed as the ones related to the smoothness or complexity of the movement (i.e. fractal dimension and local energy) [10].

Finally, the FI obtained from [13], showed a significant reduction for the EG after the intervention period, Figure 3 (b). This result is especially interesting since it shows that subjects that followed the exercise program did not fatigue as much as before, something that did not happen in the CG. Moreover, this makes the 30-s CST an interesting test to measure the fatigue effect thought the test duration, which is not possible with other similar tests such as the timed up and go or the five times sit-to-stand.

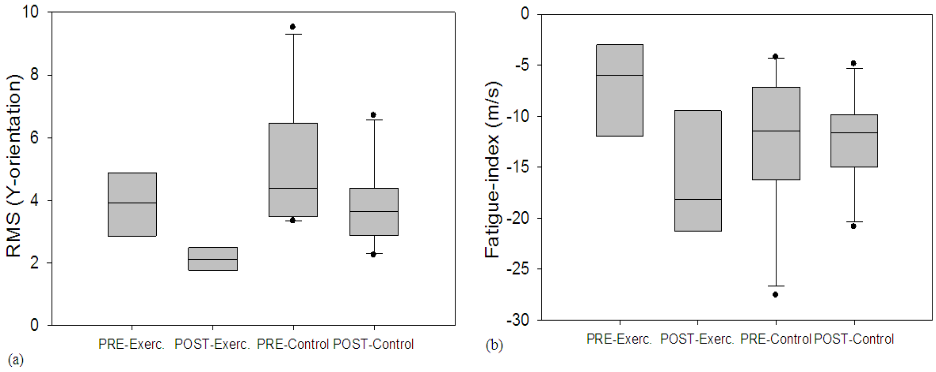

Fig. 3. Box-plots of the new-evaluated parameters: (a) RMS value of the Y-orientation and (b) fatigue index before and after the exercise intervention for both EG and CG.

5 Conclusion

The proposed approach was able to successful assess changes in postural transitions while the 30-s CST resulting from an exercise-program using the data from a single IU attached on the lower back. The methodology developed in the present study extends current knowledge in kinematics analysis in providing additional parameters such as the RMS values of not-effective directions of the movement or the FI. However, this observations needs to be further investigated to determine the effect in clinical and rehabilitation evaluations.

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