Validity of a simple sit-to-stand method for assessing force-velocity profile in older adults

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Title of the paper

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ABSTRACT

Background: Lower limb muscle strength is an important determinant of physical function in older adults. However, its measure in clinical settings is limited because of the requirement for large-scale and costly equipment. A new simple protocol based on sit-to-stand test (STS) is developed to measure force velocity (*F-v*) and power velocity (*P-v*) profile in the community-dwelling older adults. **Objective**: The objective of this study was to assess the validity of this new methodology for measuring *F-v* and *P-v* profile compared to the gold standard isokinetic BIODEX. **Participants**: 46 older people aged 65-85 years (M = 73.7; SD = 7.7). **Methods**: *F-v* and *P-v* profiles were assessed in participants on their dominant leg. The concurrent validity of STS was tested using Spearman's rank correlation coefficient and Passing Bablok: maximal power output *Pmax*, optimal velocity and force *Vopt* and *Fopt*, maximal force at null velocity *F0*, maximal unloaded velocity *V0* and coefficient of *F-v* (S_{FV}) and *P-v* equation (*a_poly*, *b_poly)*. **Results**: No proportional difference for *F0 and b_poly* and a low significant correlation for *Pmax* (r = 0.314), S_{fv} (r = 0.229), *a_poly* (r=0.335) and *b_poly* (r= 0.226) whereas the other parameters were non correlated significantly. C**onclusion**: STS method is moderately reliable on force and power parameters whereas further improvements are needing for velocity parameters. However, its feasibility, portability and lower cost compared to other methods makes it very affordable in clinical context and will allow easy investigation of aging population.

Keywords: Force-velocity relationship, simple method, clinical evaluation, sit-to-stand, ageing

1 INTRODUCTION

The "power-force-velocity" approach is based on force and power-velocity (*F-v* and *P-v*) relationships characterizing maximal mechanical capabilities of lower limbs' neuromuscular systems [1,2]. For now, individual *F-v* profile is widely used in sport performance as it give an optimal individual *F-v* profile that maximizes lower limb ballistic performance which allows individual determination of force or velocity deficit. These profiles could be very interesting to replicate in geriatrics and aging research as measures of muscle function could allow to screen for an age-related loss of muscle strength and power. Indeed, a loss of muscle function is related to frailty [3], risk of disability [4], and morbidity in older people, all of which can lead to a loss of independence in older people.

To date, Gold Standard for measuring muscle function in clinical practice and research settings is isokinetic dynamometry [5]. Nevertheless, those systems that measure force and velocity with accuracy are very expensive and time-consuming which limit their spread in clinics. The recent technological progress involving wearable sensors opens the field of possibilities and allows to replace those costly systems with convenient, simple and accurate analysis of the biomechanical kinematic variables. Samozino et al [6] developed their own simple method for having power-force-velocity profiles which can be determined from a series of 2 to 6 loaded vertical squat jumps. In geriatrics, a more adapted exercise is the sit-to-stand (STS) test which is widely used to assess muscle strength [7,8]. Although time to complete STS is the primary measure of function, leg velocity and muscle power also contribute to understanding physical performance but require more sophisticated, time-consuming and expensive assessment tools such as force plates [9] and/or motion capture system. To avoid those systems, many studies have attempted to evaluate STS movements with either single or multiple accelerometers, both embedded and in smartphones, placed over different regions of the human body [10,11,12]. Rojas et al [13] characterize velocity profile during STS transitions with an embedded smartphone placed on L2/L3 vertebrae region while Lepetit et al [14] used a single magneto-inertial measurement unit fixed on the chest to quantify velocity, acceleration and kinematic data. All these studies only measure one parameter over leg power, force and velocity which does not allow the assessment of *F-v* and *P-v* profiles. To our knowledge, the only study that combines everything is Ruiz-Cardenas et al [15]. They developed an App technology to objectively measure time, velocity and leg power during a single STS test. The App was designed for analysing STS via highspeed video recording (240 frames-per-second) allowing the calculation of time between two frames selected by the user and subsequent calculation of mean vertical velocity and vertical power relative to body weight.

Nowadays, the spread of technology enable the development of simple method by only using smartphones or simple devices. Recently, an open library for real-time multi-person key point detection was proposed by Carnegie Mellon University named OpenPose. It is a real-time system to jointly detect 130 human body, hand and facial key points on single images. In addition, its computational performance on body key point estimation is invariant to the number of detected people in the image with high accuracy. OpenPose is freely available for all kinds of free non-commercial use [16]. This library enable to have every single joint of the body, angular velocities of the joint, and lower limb forces. In our knowledge, yet, no study has used OpenPose to calculate lower limb force and velocity on STS.

As STS has already proved its worth as an effective tool for assessing F-v profiles in clinical geriatric and as OpenPose seems to be a promising one also, combining the two could result in an effective simple method. In this context, the aim of this study was to propose and validate a new simple protocol for determining the *F-v* and *P-v* profiles in the hope of using it to detect decline in physical abilities in older adults. The concurrent validity of this method was tested by comparison to reference isokinetic protocol. We hypothesized that force and power variables will be moderately correlated, velocity variables will be poorly correlated with linear association between them reflecting a sufficient concurrent validity.

2 MATERIALS AND METHODS

2.1 PARTICIPANTS

A total of 109 community-dwelling older adults aged between 65 and 85 years old were recruited. Exclusion criteria were pathologies that prohibit a maximal strength test, such as severe cardiovascular disease, artificial hip or knee, acute hernia, infection, or tumour. All participant gave written informed consent. Thirty acquisition were not well recorded during STS due to some improper Openpose detection caused by the camera angle, leading to missing data at some velocities (0, 5 or 10kgs). Also, Grubbs test [17] detected 33 recurrent outliers (abnormal STS parameters) resulting in their removal. Finally, 46 participants (6men, 40women) were included in this study (mean age = 73.7 +/- 7.7 years; mean height = 161.8 +/- 8.2 cm; mean weight = 61.5 +/- 11.4 kgs; mean BMI = 23.5 +/- 4.2 kgs/m²).

2.2 EXPERIMENTAL PROTOCOL

Participants were drawn from the *Frailty* project, which aims to identify multidisciplinary markers of aging. Approval of the study protocol was obtained (*n° 2015-A01188-41*). The protocol consists of evaluating *F-v* profiles with Biodex dynamometer system 4 (Biodex Medical Systems, Inc., Shirley, NY) and with STS simple method. The side of healthy or dominant leg for *F-v* profile evaluation was chosen to fit with the unilaterality of BIODEX. Thus, hip and knee prosthesis, knee arthrosis and other pathologies were avoided. The protocol included two standardized tests in the following order: STS protocol and Biodex protocol. During each test, participants were clearly instructed by the test leader to perform with maximal effort.

2.2.1 Sit-to-stand protocol

The tool used was an adjusted chair without backrest. The seat height was visually adjusted to allow the participant to start with a 90° knee angle. A visual line was also placed on the ground to limit feet's displacement during the test. Participants were initially seated on the chair with their back in an upright position wearing their own shoes (in an ecologically situation) (Figure 1). Then, they were instructed to stand up as fast as they can with their arms folded across their chest in 3 conditions: with no additional load, with 10kgs load and with 5kgs. All trials were performed using the same chair and with similar ambient conditions. They repeated it 3 times to assure to reach maximal velocity during STS and the best of the 3 trials was taken. Resting time between the 3 conditions was sufficient to prevent participant from fatigue. A camera was positioned to follow STS movement on their dominant leg unless there was a medical contraindication.

2.2.1.1 Analysis procedure and data recording to sit to stand protocol

Acquisitions were recorded with an Ipad (30hz, 1280x720p). The videos were processed on Python with OpenPose library [16]. This library can detect multiple people in real time which is the first time a library can jointly detect key points on human body, face, and foot. The protocol setup was to collect measurements from iPad, to retrieve key points by applying OpenPose “Body25 model” on videos, to preprocess (denoising, calculating kinematic parameters) and finally to calculate *F-v* and *P-v* profiles. To determine the time point for starting and ending the movement during STS test, plateau were detected on knee flexion extension kinematics. A 0° plateau corresponded to the end of the STS (full extension and a 90° to the start of the movement. The starting point of the STS was determined when a plateau at 90° on knee flexion kinematics was detected. The ending point was defined when full extension of knee was achieved in an upright stance corresponding to a 0° plateau. All the F-v and P-v parameters were calculated for one leg to allow comparison with the unilateral single joint BIODEX. With OpenPose, the coordinates (X, Y) over time for shoulder, hip and knee were taken allowing the calculation of their velocities. The associate thigh and body force (eg reaction force) for one leg were calculated as followed as well as power P:

F_{thigh}= *0.1416**p*g

F_{upper_body}= *0.6028**(p+charge)*g

With g the gravitational force (9,81 N/kg), p the weight of the participant (kg), charge could be 0, 5 or 10kgs depending on the wearing jacket and 0.1416 and 0.6028 were taken from the anthropometric De Leva’s table [18].

P = $M_{upper\_body} * v_{upper\_body} + 2 * (M_{thigh} * v_{thigh})$

with $M_{\_upper\_body}$ *the net moment joint (*F_{upper_body}**d),* M_{thigh} *as* F_{thigh} **d and v the angular velocity of the upper body and thigh respectively.*

2.2.2 Isokinetic protocol

Measurements were performed unilaterally on the same side of STS protocol. Participants were seated on a backward- inclined (5°) and adjustable chair, which is part of the dynamometer (Figure 1). A strap was applied across thigh and hips and shoulders were stabilized with safety belts to avoid additional movements. The rotational axis of the dynamometer was aligned with the transversal knee-joint axis and connected to the point of force application at the distal end of the tibia (i.e. 5cm above the lateral malleolus) using a length-adjustable rigid lever arm. Range of motion was set from a knee joint angle of 90° to 160°, with a full extended leg corresponding to a 180° knee angle. Participants were evaluated at six different velocities: 180°/s, 150°/s, 120°/s, 90°/s, 60°/s, 30°/s to reach an accurate *F-v* profile. Before starting the evaluation, participants performed repetitions to familiarize with knee extension movement and to warm-up.

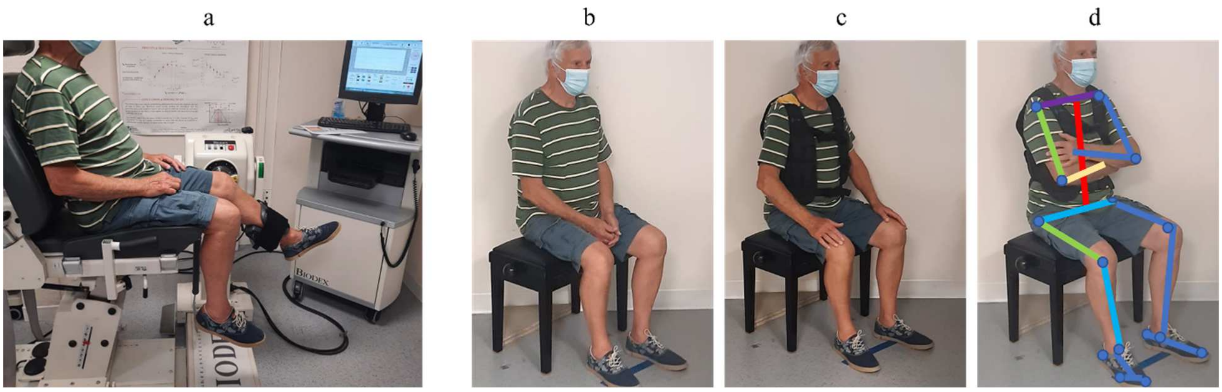

Figure 1: Isokinetic BIODEX positioning of the participant (a) and STS protocol at 0kgs (b), 10kgs (c) and 5kgs with OpenPose skeleton fitting specific body point (d).

2.2.2.1 Analysis procedure and data recording for isokinetic protocol

Sampling was performed at 100 Hz using an electronic interface card (Biodex Medical Systems Inc., X2151, Shirley, NY, USA). The evaluation on the six different velocities allows to obtain a set of parameters such as the ratio between agonist and antagonist muscles as well as curves representing *F-v* and *P-v* relationships.

Force (*F*) – velocity (*V*) relationship was described by a first order linear equation:

$$\boldsymbol{F = S_{FV} \cdot V + F0}$$

with S_{FV} and *b_linear* the coefficients of the polynomial relation. Note that *F0* is a force corresponding to the theoretical moment at 0° /s velocity value. The velocity value which corresponds to 0 Nm was the maximum theoretical velocity (V_{MAX}).

Power (*P*) - velocity (*V*) relationship was described by a second order polynomial equation:

$$\boldsymbol{P = a\_poly \cdot V^2 + b\_poly \cdot V}$$

with *a_poly* and *b_poly* coefficients of the polynomial relation (Figure 2).

Maximum power (P_{MAX}), and optimal velocity (V_{OPT}) were determined from this equation as:

$$\boldsymbol{V_{OPT}} = -\frac{\boldsymbol{b\_poly}}{\boldsymbol{2 * a\_poly}} \text{ and } \boldsymbol{P_{MAX}} = -\frac{\boldsymbol{b\_poly^2}}{\boldsymbol{2 * a\_poly}}$$

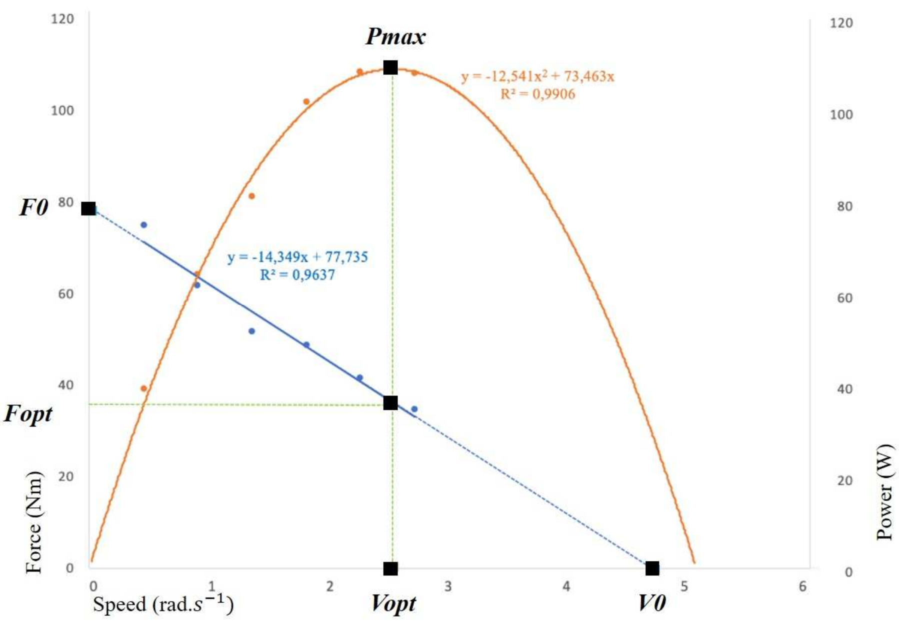

Figure 2: Force-velocity (F-v) and power-velocity (P-v) profiles

2.3 DATA ANALYSIS AND STATISTICAL CALCULATION

All statistical method comparison was made on *F-v* and *P-v* parameters which are *Pmax, Fopt, Vopt* and *V0*. We also compared coefficient of *F-v* and *P-v* equation which are *a_poly* and *b*_poly defined as the quadratic and linear coefficient respectively of *P-v* equation and S_{fv} and *F0* defined as the slope and the constant of the linear *F-v* equation. All data were screened for normality using the Shapiro Wilk test. Concurrent validity between STS and BIODEX was assessed by determining Spearman's rank correlation coefficient (r) . The following correlation classification was used: negligible r=0-0.10, low r=0.10–0.39; moderate: r = 0.40–0.69; high: r = 0.70–0.89; very high: r = 0.90–1.0 [19]. Passing-Bablok regression was used to assess the linear association between parameters that succeed to CUSUM test (p>0.05) [20]. All statistical tests were regarded as significant at p<0.05 with a Benjamini-Hochberg correction for multiple associations and statistical analyses were performed using XLSTAT (Addinsoft, New York, USA).

3 RESULTS

Mean ± Standard deviation for both STS and BIODEX methods for mean force, velocity and power output are presented in Table 1. Spearman's rank correlation showed no to very low (r= -0.024-0.226) and non-significant (p=0.08-0.77) for most of the parameters except for *Pmax* (r = 0.314), S_{fv} (r = 0.229), *a_poly* (r=0.335) and *b_poly* (r=0.226) (Table 1). Finally, for all parameters except for S_{fv}, p-value of the CUSUM test was more than 0.05 (Table 1) concluding in a linear relation between the two methods. We were thus able to use Passing Bablok regression analysis presented in Figure 3.

The intercept value in Table 2 is a measure of systematic differences between the two methods. The 95% confidence interval containing the value 0 means no systematic difference between the two methods which is not the case for *Pmax, Vopt, F0*, *V0,* S_{fv} and *a_poly*. Then, it is concluded that the difference between STS and the reference BIODEX method differs at least by a constant amount. For *Fopt* and *b_poly*, the confidence interval is respectively [-111.9; 0.3] and [-123.1; 1.04] concluding in no systematic difference between STS and BIODEX.

The slope coefficient in Table 2 is a measure of proportional differences between the two methods. The 95% confidence interval for the slope including 1 means no proportional difference is found. For *Pmax*, *Fopt*, *Vopt*, *V0,* S_{fv} and *a_poly*, any of the confidence interval contains 1 concluding in a proportional difference between the two methods whereas for *F0*, and *b_poly*, no proportional difference between the two methods was found.

Table 1: Mean ± Standard deviation and concurrent validity between both methods for mean force, velocity, and power output in one leg.

	Biodex (reference measures)	STS	Spearman's r coefficient	CUSUM test for linearity
Pmax (W)	143.9 +/- 49.9	187.5 +/- 147.3	0.314*	0.124
Vopt (rad/s)	3.6 +/- 0.8	3.3 +/- 3.3	-0.043	0.621
Fopt (N)	39.5 +/- 14.9	36.3 +/- 37.9	0.161	0.05
F0 (N)	83.1 +/- 28.5	62.3 +/- 42.6	0.199	0.387
V0 (rad/s)	7.1 +/- 2.1	6 +/- 7	-0.024	0.109
S_{fv}(N.s.m^{-1})	-12.7 +/- 5.1	-4.4 +/- 11.6	0.229*	0.021**
a_poly	-12.7 +/- 5.1	-4.1 +/- 11.7	0.335*	0.05
b_poly	81.7 +/- 28.7	61.8 +/- 43.3	0.226*	0.621

Pmax: Maximal power output against different loading conditions
Vopt: optimal velocity to reach maximal power
Fopt: optimal force to reach maximal power
F0: the theoretical maximal force at null velocity,
V0: the theoretical maximal velocity at which lower limbs can extend during one extension under zero load
S_{fv} **:** slope of the F-v relationship
a_poly, b_poly: coefficient of the P-v relationship
* Significant correlation ($p<0.05$) (p_value < B-H adjusted p_value)
** non-linear relation between the two methods ($p < 0.05$) (Passing Bablok not applicable)

Table 2: Passing Bablok model coefficient for Pmax, Vopt, Fopt, F0, V0, S_{fv} , a_poly and b_poly

	Intercept value (95% confidence interval)	Slope coefficient (95% confidence interval)
Pmax (W)	-182 [-408 ; -45.1]	2.4 [1.5 ; 4.2]
Vopt (rad/s)	75.4 [0.7 ; 8.08]	-20.9 [-1.6 ; 0.4]
Fopt (N)	-42.9 [-111.9 ; 0.3] a	2.3 [1.1 ; 4.1]
F0 (N)	-50.7 [-155.2 ; 0.7]	1.4 [0.7 ; 2.8] b
V0 (rad/s)	42.3 [5.1 ; 19.3]	-5.8 [-2.3 ; -0.13]
S_{fv} (N. s. m^{-1})	23 [47.8 ; 9.3]	2.2 [1.1 ; 4.4]
a_poly	22.6 [41.1; 12.2]	2.4 [1.4 ; 3.2]

b_poly	-73.4 [-123.1 ; 1.04] a	1.7 [0.7 ; 2.4] b

a No systematic difference between the two methods
b No proportional difference between the two methods

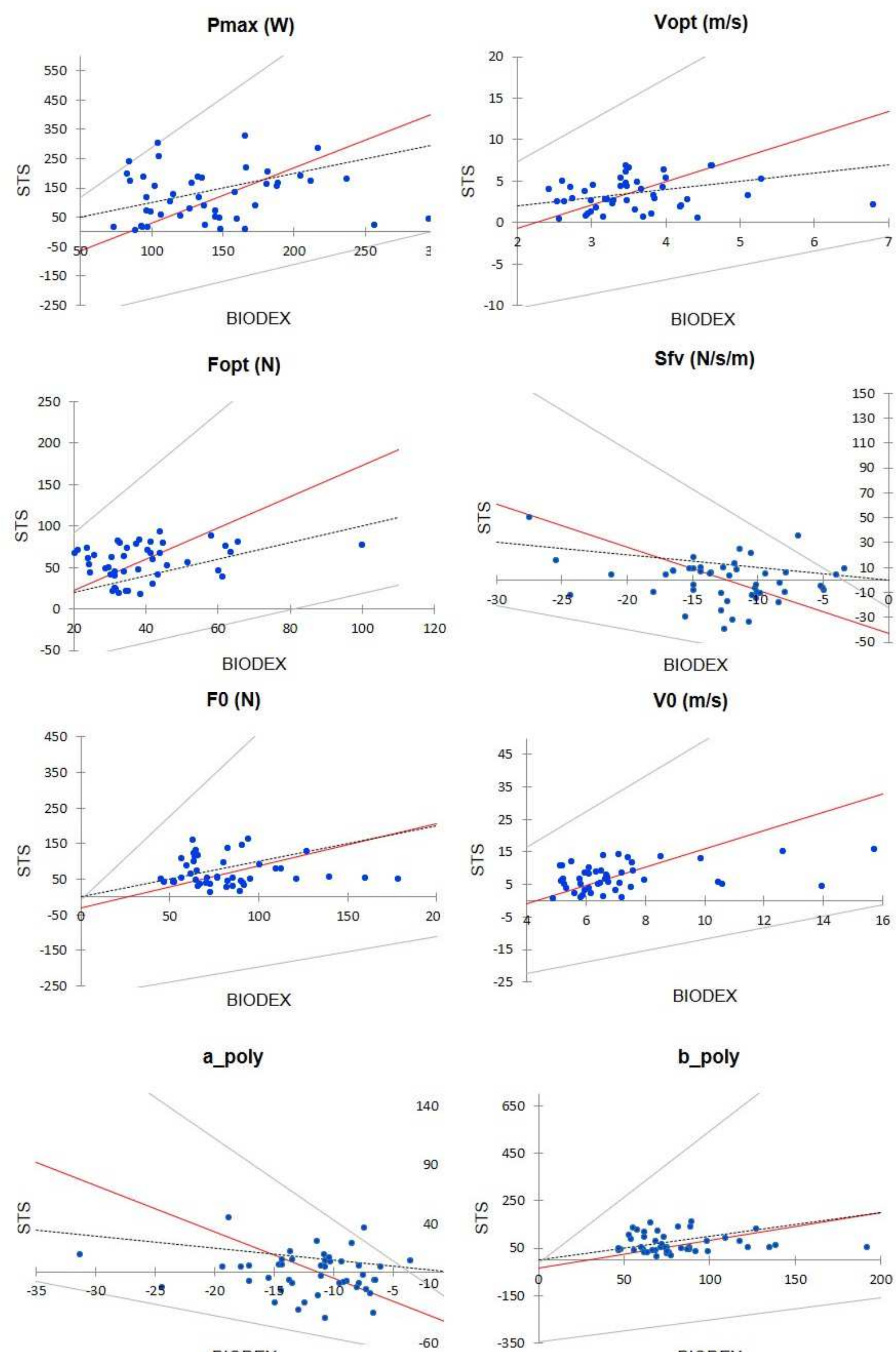

Figure 3: Passing Bablok regression analysis of the two methods, STS and the reference BIODEX, for Pmax, Vopt, Fopt, F0, V0, Sfv, Fmax, a_poly and b_poly. Scatter diagram with regression line and confidence bands. Identity line is dash

4 DISCUSSION

The objectives of this study were to assess the concurrent validity of a new method to assess *F-v* and *P-v* profiles in older adults based on STS protocol comparing it with the well-known isokinetic protocol. Results obtained highlighted a linear relationship between most of the *F-v* and *P-v* parameters between the two methods, no proportional difference for *F0 and b_poly* and a low significant correlation for *Pmax* (r = 0.314), S_{fv} (r = 0.229), *a_poly* (r=0.335) and *b_poly* (r=0.226) whereas the other parameters were non correlated significantly. Results are, thus, encouraging showing a fairly low concurrent validity for parameters of force, power and slope of F-v and P-v relationship (S_{fv}, *a_poly* and *b_poly* respectively).

Spearman's rank correlation was significant but quite low for *Pmax* (r = 0.314, p = 0.017), S_{fv} (r = 0.229, p=0.065), *a_poly* (r=0.335, p=0.012) and b_poly (r=0.226, p =0.065) whereas incongruent and non-significant correlation were found for the other parameters. Impellizzeri et al. also found a quite low correlation for peak force by comparing a jump test with an isokinetic leg extension (r = 0.48, 95%CI: 0.26-0.66) [21]. But when compared to a more similar test (pneumatic leg extension), the correlation is stronger (r=0.83, 95%CI = 0.7-0.91) [21,22,23]. In view of these results, results are consistent with the literature and the difference between the two protocols, BIODEX and STS, may strongly impact on the agreement between F-v and P-v parameters. Indeed, when one method (BIODEX) recruited one leg in a closed kinematic chain (isolate knee joint), the other (STS) recruited two legs in open kinematic chain (multiple joints participating to the movement). Studies have demonstrated that mechanical output in leg multi-joint movement is different from that in a single- joint exercise [24]. However, even if methods are quite different, the agreement in *Pmax,* thus the STS calculation, is quite consistent with previous results which highlight the capacity of the STS method to determine the mean peak force in community-dwelling older adults. Indeed, the range of magnitude of *Pmax* between BIODEX and STS were very similar (M= 143.9W, SD= 49.9W; M=187.5 W, SD=147.3W for BIODEX and STS respectively). The 187.5W found during the STS was for one leg which gave approximately 375W for the entire power developed by the two legs during the STS movement. This value was compared to other studies that used different methods for Pmax calculation to check the consistency of this study's protocol. Regarding the range of magnitude, the study's Pmax appeared to be very closed to the 400W value found in other studies highlighting the consistency of this value [25,26].

The high variability in *Pmax* represented by a SD of +/-147.3W (more than 75% of variability) should also be noticed as, for other studies using STS test, the variability was lower (around 40% in *Pmax* variability) [27]. The high variability obtained here, which is also extended to all STS parameters, can be partly attributed to the STS design protocol used in this study. Indeed, a reasonable variability was found for BIODEX parameters when the range of movement was individually adjusted allowing participants to start with a precise 90° knee angle. Also, when Alcazar et al [27] used a standardized armless chair (0.49 m height), a 40% variability was found. In this study, knee angle was not precisely measured even if the start position during STS was visually corrected by the investigator. The starting position visually adjusted was at 85° as a mean in all the participants which highlight that the visual placement at 90° is not perfect. To improve precision, future studies should use the video recording and Openpose to directly correct knee angle and re-adjust chair height to allow participant to begin STS with a precise 90° knee angle which can be done in live. The high STS variability is also explained by the protocol itself where the STS parameters were very dependent to the patient stand up velocity whereas for the BIODEX, the patient had to simply follow the pace and the fixed velocity. This contributes to more technical variation in STS execution leading to a high intra-variability thus a lower reliability.

The high variability is also participating in the lower reliability results found especially in velocity parameters (*Vopt* and *V0*) where no proportional and systematic difference was found in Passing Bablok. Several studies in young and older adults have also reported lower agreement values for *V0* [28,29,30,31,32]. This could be attributable partially to the STS method itself to assess F-v profiles. Indeed, while the F-v profile was assessed by using multiple point (i.e. 6 velocities), the STS was using three points (0, 5, 10kgs). Janicijevic et al [32] have recently shown a low concurrent validity of the two-point method, which is quite similar to the three-point, for *V0* and *F0*. When moving from multiple-point methods (usually 4 to 6 velocities or loads) to a two-point method (or a three-point), the extrapolation between the two-points to construct *F-v* and *P-v* slopes is wider than the multiple points providing a larger range of force and velocity data thus a large extrapolation error risk [32]. Also, the model used to fit the *F-v* relationship was the linear model over all the sample (from 0 to 100% of *F0*) which was largely used in other studies [6,33]. This can be debatable as the linear equation was found to exceptionally fit the F-v shape only between 45 to 100% of *F0* [34]. Many models have been proposed to fit the F-v relationship with a hyperbolic equation as Hill et al proposed [35] when others demonstrated that the relationship was deviated from this rectangular hyperbola at forces close to the maximal isometric force and that a double-hyperbolic equation was better [36]. It is understandable that the misconception of the shape of the F-v relationship can lead to serious errors in the estimation of several parameters derived from linear equations, such as *F*0 and *V0*. However, despite this questionable choices, the shape of the STS F-v and P-v equation (*Sfv* and *a_poly* respectively) was found to be correlated (r=0.229-0.335) while other studies found inconsistent results for them (p>0.05) [30,32].

Although results are similar to previous works, this method presents some limitations. First, participants were filmed in a side view bounding Openpose on one side to calculate kinematics. This could have increase the risk of losing data or abnormal recording if the subject was not well detected. When missing data appeared, it results in extrapolation when calculating F-v parameters that could partially explained the incongruent correlation obtained [28,29]. An improvement could be to place the participant at 45° to the camera to allow Openpose to refer to both right and left sides in order to improve detection thus reliability on calculation. Another limit is that absolute fixed loads were used (5 and 10kgs) instead of relative to body weight to simplify the protocol. It appeared not to correspond to some patients which were removed from the study as the hypothesis of reducing velocities with heavier loads was not always respected. It was for only 30% of the participants but to reduce exclusion, a real time feedback on movement velocity should be given during STS to be sure the hypothesis is well respected [37]. Finally, the study design did not allow for a test-rest reliability on STS but previous results seem promising. Indeed, many studies have tested reliability of a STS power test which appears to be excellent (ICC=0.96) [22,23]. Future studies should, therefore, test reliability on other *F-v* parameters than power. It is therefore likely that the observed limited validity in the F-v parameters especially in velocity parameters are caused by extrapolation error and the combination of technical/instrumental and biological variations that could be easily rectified.

However, for a measurement tool to be widely accepted, factors such as feasibility, safety, and cost are just as, if not more, important than measurement properties. Several tools have been used to assess *F-v* and *P-v* profiles in older adults but are very expensive and time-consuming. Indeed, an isokinetic ergometer is feasible with older adults but will take long time (at least 20mn for warm up and protocol) and is overpriced (around 80 000$). A method based on loaded and unloaded squat jump was developed by Samozino et al [6] to assess *F-v* and *P-v* profiles with low-cost materials. It has shown to have sufficient validity and reliability but there remains safety and feasibility concerns, especially in low functioning older adults. This study was, to our knowledge, the first to propose and validate STS protocol to assess *F-v* and *P-v* profiles in older adults and follows in the footsteps Balachandran et al [22] who succeed to develop STS power test in older adults. This method is portable, quicker (around 10mn for the all protocol) and less expensive (estimated at less than 300$) than the existed methods.

As a conclusion, we found better correlation in variables of force and power but not significant in velocities and we shared the same conclusion with better results as other studies that have reported lower or no reliability values for *V0*, *Pmax* or *Sfv* [30,32]. The simple computation method proposed here might offer an inexpensive and easy alternative to assess and individualize *F-v* profiles without the need of expensive technologies in community-dwelling older adults. Future research should investigate if the method is consistent to detect frailty among older adults or future fallers based on *F-v* and *P-v* profiles.

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