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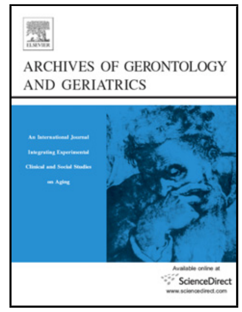

Title: Bilateral deficit in explosive force related to sit-to-stand performance in older postmenopausal women.

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Running head:

Bilateral deficit related to chair rise time.

Highlights

- BLD in explosive force rather than maximal force is associated to STS performance.
- The impact of BLD on STS depends on the level of physical activity.
- The rise force development is functionally more important than maximal force.

Abstract

The purpose of this study was to determine whether the bilateral deficit (BLD) for maximal voluntary force (MVF) and rate of force development (RFD) influences sit-to-stand in older postmenopausal women. Fourteen women performed unilateral and bilateral maximal voluntary contractions during isometric leg-extension. The MVF and RFD over consecutive 50ms periods (0-50, 50-100 and 100-150ms) after force onset and the time to sit-to-stand test were calculated. There was only a BLD for RFD 0-50ms and 50-100ms. The time of sit-to-stand was moderately correlated to BLD for RFD 0-50ms (*r*=0.505; 95% CI: -0.035 to 0.817; *P*=0.06), but after controlling for physical activity level the relationship was stronger and statistically significant (*r*=0.605; 95% CI: 0.109 to 0.859; *P*=0.029). These results suggest that the BLD for explosive force (0-50ms) might represent a performance-limiting factor for sit-to-stand transfer in postmenopausal women and could be dependent of the physical activity level.

Trial registered at Clinical Trials Gov.: NCT02434185.

Key words: muscle strength, rate of force development, activities of day living, bilateral index

1. Introduction

Aging is commonly associated with a natural decline in maximal and explosive muscle strength (Häkkinen et al., 1996; Jubrias, Odderson, Esselman, & Conley, 1997) characterized by structural changes in the neuromuscular system in both men and women. The substantial decrease in estrogen levels due to menopause, seemingly contribute to greater age-related decline in women compared to men (Cipriani et al., 2012; Lang, 2011). There are a number of elements across the neuromuscular system that contribute to generating force, but it seems that the mere act of adding a limb alters the interrelationship of these elements and negatively impacts force production. The bilateral strength deficit (BLD) represents the reduction in performance during synchronous bilateral limb contractions compared with the sum of identical unilateral limbs contractions (Jakobi & Chilibeck, 2001). This phenomenon has been shown in both upper and lower limbs, for a variety of static and dynamic contractions involving both large and small muscle groups, and is usually larger for rate of force development (RFD) than for maximal voluntary force (MVF) (Buckthorpe, Pain, & Folland, 2013; Cornwell, Khodiguian, & Yoo, 2012; Sahaly, Vandewalle, Driss, & Monod, 2001; Van Dieen, Ogita, & De Haan, 2003). However, the underlying cause of this deficit remains equivocal, but evident regardless of age (Hernandez, Nelson-Whalen, Franke, & McLean, 2003; Yamauchi, Mishima, Nakayama, & Ishii, 2009).

Several authors have suggested that the occurrence of a BLD could have a significant impact on functional capability of bilateral movement tasks (Hernandez et al., 2003; Pääsuke et al., 2004; Samozino, Rejc, di Prampero, Belli, & Morin, 2014) but this hypothesis has not been evaluated. Pääsuke et al. (2004) reported that the BLD for MVF was positively correlated with the time to rise from a chair ($r = 0.60$; $P < 0.05$) in older women with Parkinson disease, but this relation was not evident in age- and sex-matched controls. However, explosive force, calculated as RFD, is often considered functionally more relevant than isometric peak force in understanding and predicting functional ability in everyday activities (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Suetta et al., 2004) and because it slows more in bilateral compared with unilateral contractions (Buckthorpe et al., 2013; Cornwell et al., 2012; Sahaly et al., 2001; Van Dieen et al., 2003) it should be evaluated relative to tasks that predict functional mobility in older adults.

The purpose of this study was to assess whether sit-to-stand (STS) performance is associated with BLD in MVF or RFD in older postmenopausal women. It was hypothesized that BLD for explosive force would constitute a performance-limiting factor during STS whereas the BLD relative to maximal voluntary force would not contribute to performance differences.

2. Material and methods

2.1. Study design and participants

A cross-sectional experimental design was applied to assess the role of BLD on the STS transfer (ClinicalTrials.gov Identifier: NCT02434185). Fourteen women who had experienced one year of primary amenorrhea (62.1 (SD: 5.16) yrs; 1.55 (SD: 0.062) m; 67.2 (SD: 9.28) kg; 28.13 (SD: 4.66) kg/m^2) volunteered to participate. They had not undertaken endurance or resistance training, but were without musculoskeletal, neurological or cardiovascular limiting-diseases. The physical activity level of the subjects was measured with Spanish Short Version of the Minnesota Leisure Time Physical Activity Questionnaire (SSVM), five meter walking test (5 MWT) and grip force (Table 1). All participants were informed about the study objectives, potential risks and benefits, and informed consent was signed prior to participation. All procedures conformed to the Declaration of Helsinki and this study was approved by the Research Ethics Committee of the Catholic University of Murcia, Murcia, Spain.

2.2. Procedures

Participants attended the laboratory on two separate occasions, once for familiarization with the procedures and one-week later for the experimental session. The two sessions involved an appropriate warm-up composed of 2-3 STS, 2-3 submaximal isometric leg extension contractions, followed by 2-3 maximal isometric voluntary contraction in each condition (bilateral and unilateral). The experimental session involved the measurement of STS and execution of bilateral and unilateral isometric leg extension.

2.2.1. STS transfer

Subjects sat on an unsupported backrest chair with their arms resting over their legs with the hip, knee and ankle joint at approximately 90º. Each foot rested on a force plate (*Kistler 9286BA, Kistler Instruments, Amherst, NY, USA*) and they were instructed to stand up as fast as possible. Vertical force was sampled at 1000Hz from the force plate. Two trials were performed and the trial with the highest ground reaction force, as per prior studies (Lindemann et al., 2003), on the vertical axis was selected for analysis.

2.2.2. Leg extension task

The subjects were carefully familiarized with the test procedures of maximal voluntary force production during several sub-maximal warm-up contractions with five-minutes of rest to avoid fatigue. Force was recorded with a strain gauge (*Noraxon DTS Force sensor 500lb-F 2200N, USA*) secured to the carriage of a horizontal leg press machine (*Technogym® Leg-press, Cesena FC, Italy*) and sampled at 1500Hz. Subjects were positioned on the horizontal leg press with the knee and ankle joint positioned to 90º with arms crossed over the chest. Instructions were given to produce MVF (bilateral, left unilateral and right unilateral, randomized order) as hard and fast as possible. On-line visual feedback of the instantaneous force signal was provided to the subjects on a computer screen placed ~2m in front and at eye level with the subject. Five minutes rest was given between each MVF. Any trial with pre-tension observed during the force-time curve was discarded. Two satisfactory trials for each condition (bilateral, left unilateral, right unilateral) were performed and the trial with maximal peak force was selected for off-line analysis.

2.3. Data Analysis

Force plate data were stored and analyzed off-line using BioWare software (*KistlerBioWaresoftware version 5.3.0.7, Winterthur, Switzerland*) and strain gauge data using myoMUSCLE software (*Noraxon company, version MR 3.6 myoMUSCLE Essential software, USA*) for Microsoft Windows XP professional (*Microsoft Windows XP professional Service Pack 2, Redmond, WA*).

The time necessary to sit-to-stand (T_{STS}) was calculated as previously described (Lindemann et al., 2003). The beginning of movement was defined as the decrease of vertical force by more than 2.5% body weight depression on the platform and the end of movement was the point in which the vertical force reached stable body weight depression on the platform.

The maximal voluntary isometric force (MVF) was calculated as the maximal value achieved during leg extension tasks for bilateral, left unilateral and right unilateral efforts and normalized to the participant's body mass (N/kg).

The rate of force development (RFD) was derived as the average slope of the force-time curve (dforce/dtime) and was measured over three consecutive 50 ms time periods from the onset of force (RFD_{0-50}, RFD_{50-100}, $RFD_{100-150}$) for the bilateral, left unilateral and right unilateral leg extension tasks (Buckthorpe et al., 2013). Onset of muscle contraction was defined as 2.5% of the difference between baseline moment and MVF (normalized RFD) (Aagaard et al., 2002).

Bilateral indices for MVF (BI_{MVF}) and rate of force developed (BI_{RFD}) over three consecutive 50 ms time periods from the onset of muscle contraction were calculated to express any relative difference in force output between unilateral and bilateral conditions. The calculations were performed as:

BI% = [100x(bilateral)/(left unilateral + right unilateral)] – 100 (Howard & Enoka, 1991)

A divergence of the BI from zero demonstrated that there was a difference between the unilateral and bilateral conditions. A BI which is negative indicates that the bilateral performance is less than the combined unilateral performance. A BI which is positive, is indicative of a greater bilateral than combined unilateral performance.

2.4. Statistical analyses

Statistical analyses were performed using IBM SPSS Statistics 19.0 (IBM SPSS Inc. USA, 2010). Descriptive statistics were calculated to assess the physical characteristics of the study participants. Values are given in the text as mean and standard deviation or range of the mean with 95% confidence intervals (CI). Data were normally distributed, as confirmed by the Shapiro-Wilks test. Homocedasticity was confirmed by Levene's test. A paired sample t test was used for the bilateral-to-unilateral comparison of means and a single sample t test was used to test if the mean bilateral indices were significantly different from 0. Simple linear regressions were used to analyze the relation between the time necessary to sit-to-stand and bilateral indices and determination coefficient (Pearson's linear coefficient squared) was calculated. Furthermore, in case of correlations between these variables, correlation analyses were performed for each variable after adjusting the remaining variables of physical activity as covariates; controlling the parameters of physical activity to remove their potential effect as confounding factors. We used an alpha level of 0.05 for all statistical tests.

INSERT TABLE 1 ABOUT HERE

3. Results:

3.1. Bilateral-unilateral force comparison

The unilateral right, unilateral left and bilateral forces are shown in Table 1. The summed unilateral maximal peak force did not differ from the bilateral maximal peak force (mean dif. -0.32; 95% CI: -1.415 to 0.774; *P*=0.538; Cohen's d 0.10). In contrast, there was a significant difference between bilateral and unilateral RFD at 0-50 ms (mean dif. -49.25; 95% CI: -75.63 to -22.89; *P*=0.001; Cohen's d 0.94) and 50-100 ms (mean dif. -108.85; 95% CI: -210.34 to -7.368; *P*=0.04; Cohen's d 0.54). However, the RFD did not differ between bilateral and unilateral contractions between 100-150 ms (mean dif. -93.70; 95% CI: -288.80 to 101.38; *P*=0.32; Cohen's d 0.21) (Table 2).

3.2. Bilateral indices

A bilateral force deficit was evident for BI_{RFD} (0-50 ms) (mean dif. -38.26; 95% CI: -53.91 to -22.62; *P*<0.001; Cohen's d 1.41), and for BI_{RFD} (50-100 ms) (mean dif. -26.45; 95% CI: -48.31 to -4.60; *P*=0.02; Cohen's d 0.70). However, for the BI_{RFD} (100-150 ms) (mean dif. -10.34; 95% CI: -38.85 to 18.17; *P*=0.45: Cohen's d 0.21) and for BI_{MVF} (mean dif. -1.29; 95% CI: -16.69 to 14.10; *P*=0.90; Cohen's d 0.05) a deficit was not found (Table 2).

INSERT TABLE 2 ABOUT HERE

3.3. Correlation analysis

The linear regressions models showed a statistical trend towards inverse correlation between sit-to-stand and BI_{RFD} for 0-50 ms (*r*= -0.505; 95% CI: -0.817 to 0.035; *P*=0.066). ~~with 25.5% of explained variance.~~ However, there were no correlation between bilateral indices for RFD and sit-to-stand at the later time points of 50-100 ms (*r*= -0.081; 95% CI: -0.586 to 0.47; *P*=0.784) and 100-150 ms (*r*= 0.202; 95% CI: -0.368 to 0.528; *P*=0.488). Additionally, there was no correlation between bilateral index for MVF and the sit-to-stand task (*r*= 0.160; 95% CI: -0.405 to 0.637; *P*=0.584) (Table 3).

Because physical activity levels influence task performance, such as the time rising from a chair, the correlation between sit-to-stand and BI_{RFD} (0-50 ms) was controlled for physical activity variables to remove potential confounding effect. Adjusting for SSVM or 5MWT, the influence on the correlation was minimal, however adjusting for grip force the relations was stronger (*r*= -0.605; 95% CI: -0.859 to -0.109; *P*=0.029) with 36.4% of explained variance.

INSERT TABLE 3 ABOUT HERE

4. Discussion

Studies suggest that the BLD is a performance limiting consideration for older adults due to loss of force during bilateral activities of day living (Hernandez et al., 2003; Pääsuke et al., 2004; Samozino et al., 2014). Pääsuke et al. (2004) reported that BLD in MVF was positively correlated with performance of rising from a chair (r= 0.60; P<0.05) in older women with Parkinson disease, but this relation was not evident in age- and sex-matched controls. Our MVF results are consistent with that observation; the bilateral index for force is not a sufficient performance-limiting factor in healthy postmenopausal women. Yet, explosive strength is a strong factor in performance during several activities of day living (Aagaard et al., 2002; Suetta et al., 2004) and there is generally a bilateral deficit for rate of force generation (Buckthorpe et al., 2013; Cornwell et al., 2012; Sahaly et al., 2001; Van Dieen et al., 2003). In this context, our results showed greater BLD in explosive strength for all time intervals tested compared to maximal peak force during isometric leg extension task, especially for the time interval 0-50 ms (38.3% vs. 1.3%). There was a moderate negative relationship between the bilateral index relative to RFD 0-50 ms and sit-to-stand performance (r= -0.505; P=0.06). This relationship was stronger and statistically significant after controlling for physical activity level, suggesting that the BLD for explosive force rather than MVF is likely a performance liming-factor during activities that require the participation of both limbs simultaneously which might predispose functional impairment in older postmenopausal women with low level of physical activity.

Bilateral homonymous limb movements are developed during activities of day living; such as rising from a chair. In several instances bilateral limb activation challenges the neuromuscular system, relative to unilateral activation, to generate maximal force leading to a bilateral strength deficit that for isometric leg extension ranges between 5 to 22% (Pääsuke et al., 2004; Sahaly et al., 2001). Although the BLD is evident irrespective of age (Hernandez et al., 2003; Yamauchi et al., 2009), it might have a greater impact on functional movement in the aged because the relative deficit in a bilateral contraction would be greater since maximal force is considerably less in older compared with younger women (Yamauchi et al., 2009). Because the women in this study were ~62 years old, the strength deficit will only become larger with increased age and the negative impact on functional ability further exacerbated. This situation is likely intensified if the BLD is referenced to explosive force because the loss in rapid force production is larger compared to maximal peak force in isometric conditions (Buckthorpe et al., 2013; Cornwell et al., 2012; Sahaly et al., 2001; Van Dieen et al., 2003). Various studies have shown a greater BLD to occur during the rising phase in force prior to peak force (Buckthorpe et al., 2013; Cornwell et al., 2012; Sahaly et al., 2001; Van Dieen et al., 2003). Similar to our findings, Cornwell et al. (2012) also reported differences between bilateral and unilateral conditions for rising phase, or explosive force, but not for maximal peak force.

During bilateral isometric contractions, aspects that contribute to enhancing explosive strength, such as a reduction in motor unit recruitment threshold and increases in motor unit discharge rates; particularly in the first 50-75ms of a contraction (Maffiuletti et al., 2016), are possibly more impaired than those that contribute to peak force. Therefore, the BLD might be most evident in the early and rapid phase of force generation.

Menopause, the permanent cessation of menstruation resulting from the loss of ovarian follicular activity, contributes to accelerate natural aging in women after the 5th decade (Messier et al., 2011). Hormonal changes coupled with structural changes in the neuromuscular system such as loss of motor units, reduction in the number and size of muscle fibers and, increased amount of non-contractile muscle tissue contribute to an inability to generate high levels of muscle strength as well as a slowed capacity to develop rapid muscle contractions (Häkkinen et al., 1996; Jubrias et al., 1997; Pereira et al., 2012). These seem to be greater when quantified through rate, rather than peak force and are more evident during bilateral movements. Janzen et al. (2006) reported a decrease in BLD from ~13% to ~7% in leg press exercise in postmenopausal women following bilateral strength training. Following the principle of training specificity subjects performing bilateral training improved bilateral muscle strength to a greater extent than unilateral strength, whereas a unilateral training protocol improved unilateral more than bilateral strength. Thus, bilateral training seemed to reduce BLD, while unilateral training contributes to an increase in this phenomenon (Botton et al., 2016; Janzen et al., 2006). Additionally, if bilateral strength training was carried out with bilateral contractions as fast as possible, muscle strength gains could be more specific, affecting explosive force which may improve the functional ability of sit-to-stand transfer (Aagaard et al., 2002; Cronin, McNair, & Marshall, 2002; Pereira et al., 2012; Ramírez-Campillo et al., 2014). Further studies should consider the relationship between the BLD in explosive force of lower limbs and the force fluctuations necessaries to restore balance after a perturbation, as this is associated with increased fall risk with age.

5. Conclusions

A BLD for explosive force is evident in the early time intervals relative to the onset of muscle contraction, whereas the for maximal peak force and RFD in later time intervals (100-150 ms) a BLD was not observed in an isometric leg extension task. Consequently, the BLD for explosive force during the early 0-50 ms phase of the rise force development could represent a performance-limiting factor for STS transfer in older postmenopausal women with low levels of physical activity.

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Conflict of interest statement

None of the authors declare competing financial interests.

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Table 1. Descriptive parameters of postmenopausal women (n=14).

Variable	Mean (SD)	95% CI	Minimum	Median (Q1 to Q3)	Maximum
		Physical activity variables			
Grip force (Kg)	27.8 (3.74)	25.62 to 29.95	23.0	28.0 (8.75 to 26.25)	35.0
SSVM (kcal/week)	3727.8 (2024.15)	2559.15 to 4896.5	990.0	3340.5 (2198.3 to 6595.0)	8793.4
5 MWT (seg)	4.8 (0.86)	4.36 to 5.36	4	5 (4.36 to 5.36)	6
		Unilateral right force			
MVF (N/Kg)	3.16 (1.94)	2.04 to 4.28	1.16	2.65 (1.62 to 4.63)	7.24
$RFD_{(0-50)}$ (N/s)	66.5 (15.53)	57.5 to 75.5	45.7	64.5 (55.3 to 74.9)	104.6
$RFD_{(50-100)}$ (N/s)	202.9 (66.67)	164.4 to 241.4	115.5	182.4 (158.4 to 230)	359.9
$RFD_{(100-150)}$ (N/s)	369.6 (138.42)	289.6 to 449.5	163.7	352.4 (252.2 to 504.5)	585.2
		Unilateral left force			
MVF (N/Kg)	2.93 (1.81)	1.88 to 3.97	0.99	2.24 (1.37 to 3.83)	7.25
$RFD_{(0-50)}$ (N/s)	63.2 (34.49)	43.3 to 83.1	22.4	56.5 (45 to 72.9)	165.0
$RFD_{(50-100)}$ (N/s)	205 (141)	123.6 to 286.5	51.1	179.9 (110.1 to 261.6)	573.3
$RFD_{(100-150)}$ (N/s)	385.6 (286.55)	220.1 to 551	63.2	321.6 (220.9 to 511.3)	1173.7
		Bilateral force			
MVF (N/Kg)	5.8 (3.24)	3.9 to 7.6	1.94	5.27 (3.32 to 6.81)	13.23
$RFD_{(0-50)}$ (N/s)	80.4 (49.08)	52.1 to 108.8	22.7	63.8 (46 to 102.9)	199.9
$RFD_{(50-100)}$ (N/s)	299.1 (205.59)	180.4 to 417.8	76.6	226.1 (148.6 to 465.4)	725.5
$RFD_{(100-150)}$ (N/s)	661.4 (514.08)	364.6 to 958.2	173.3	453.1 (327 to 1112.1)	1987.4
		Bilateral Indices			
BI_{MVF} (%)	-1.3 (26.67)	-16.7 to 14.1	-35.9	-8.5 (-24.1 to 20.6)	48.1
BI_{RFD} (0-50ms) (%)	-38.3 (27.09)	-53.9 to -22.6	-84.1	-37.8 (-60.4 to -21.4)	14.3
BI_{RFD} (50-100ms) (%)	-26.5 (37.85)	-48.3 to -4.6	-81.2	-36.3 (-57 to 11.6)	31.7
BI_{RFD} (100-150ms) (%)	-10.3 (49.38)	-38.9 to 18.2	-81.9	-29.5 (-43.7 to 18.3)	89.4

Spanish Short Version of the Minnesota Leisure Time Physical Activity Questionnaire (SSVM). Five meters walking test (5 MWT). MVF: maximal voluntary force. RFD: rate of force developed over consecutive 50 ms periods (0-50, 50-100 and 100-150 ms) from onset of muscle contraction. BI: Bilateral index. SD: standard deviation. 95% CI: 95% confidence interval. Q1: first quartile. Q3: third quartile.

Table 2. Mean differences between sum unilateral-bilateral, and bilateral index-reference (n=14).

Parameter	Mean Difference	SD	Lower 95% CI	Upper 95% CI	t-Student	df	P-value	Cohen's d
				Sum unilateral vs. Bilateral				
MVF (N/Kg)	0.32	1.90	-0.77	1.42	0.633	13	0.538	0.10
$RFD_{(0-50)}$ (N/s)	49.3	45.68	22.9	75.6	4.04	13	0.001*	0.94
$RFD_{(50-100)}$ (N/s)	108.9	175.77	7.4	210.3	2.32	13	0.037*	0.54
$RFD_{(100-150)}$ (N/s)	93.7	337.89	-101.4	288.8	1.04	13	0.318	0.21
				Bilateral Indices vs. Reference (zero value)				
BI_{MVF} (%)	-1.3	26.7	-16.7	14.1	-0.181	13	0.859	0.05
BI_{RFD} (0-50ms) (%)	-38.3	27.1	-53.9	-22.6	-5.28	13	<0.001*	1.41
BI_{RFD} (50-100ms) (%)	-26.5	37.9	-48.3	-4.6	-2.62	13	0.021*	0.70
BI_{RFD} (100-150ms) (%)	-10.3	49.4	-38.9	18.2	-0.784	13	0.447	0.21

MVF: Maximal voluntary force. RFD: rate of force developed over consecutive 50 ms periods (0-50, 50-100 and 100-150 ms) from onset of muscle contraction. BI: Bilateral index. SD: standard deviation. 95% CI: 95% confidence interval. Df.: degrees of freedom. * Differences statistically significant at an alpha level of 0.05.

Table 3. Correlations and partial correlation between the dependent variables (n=14).

Variables		T_{STS} (sec) r	95% CI	p-value	R-squared (%)
Bilateral indices	MVF (%)	0.160	-0.405 to 0.637	0.584	2.6%
	$RFD_{(0-50)}$ (%)	-0.505	-0.817 to 0.035	0.066	25.5%
	$RFD_{(0-50)}$ (%)[a]	-0.604	-0.859 to -0.109	0.029*	36.4%
	$RFD_{(50-100)}$ (%)	-0.081	-0.586 to 0.47	0.784	0.7%
	$RFD_{(100-150)}$ (%)	0.202	-0.368 to 0.662	0.488	4.1%

T_{STS}: time necessary to sit-to-stand transfer. MVF: Maximal voluntary force. RFD: rate of force developed over consecutive 50 ms periods (0-50, 50-100 and 100-150 ms) from onset of muscle contraction. 95% CI: 95% confidence interval. [a] Partial correlation controlled for grip force. * Correlation statistically significant at an alpha level of 0.05.