ORIGINAL ARTICLE

Bilateral handgrip deficit is modulated by testing sessions in strength-trained subjects

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ABSTRACT

Background: Although the bilateral deficit (BLD) is a well-documented neuromuscular phenomenon, most studies rely on single-session assessments or strength training interventions, limiting insights into motor learning and task familiarization effects. Objectives: This study aimed to examine the presence of BLD during handgrip contractions across multiple sessions and to assess differences in maximal strength between the dominant and non-dominant hand in unilateral and bilateral conditions, as well as potential sex-related differences. Methods: Thirty-seven resistance-trained participants (19 males, 18 females) performed unilateral and bilateral maximal isometric voluntary contractions (MIVCs) during a handgrip on two separate days. Results: BLD was present in the first session but absent in the second. Sex and handedness dominance did not affect this deficit, but the specific practice of the assessed task did. Conclusions: Our findings indicate that simply performing the grip BLD test significantly modulates bilateral force production. Our findings suggest the need to practice the task being assessed to objectively measure this deficit. This could be relevant from a methodological perspective in the study of this phenomenon.
Keywords: Performance analysis, Bilateral index, Sex-related differences, Dominant hand, Maximal force, Grip strength.

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INTRODUCTION

Bilateral deficit (BLD) is a well-documented neuromuscular phenomenon characterized by a reduction in maximal force output when both limbs are activated simultaneously compared to the sum of the force produced by each limb unilaterally (Henry & Smith, 1961). Due to its relevance in neuromuscular performance, this phenomenon has been extensively examined across different age groups, muscle groups, and movement patterns in both athletic and non-athletic populations within the field of sports science, biomechanics, rehabilitation, and exercise physiology (Jakobi & Chilibeck, 2001; Schantz et al., 1989; Taniguchi, 1998) BLD has been observed across various contraction types, including dynamic (Simoneau-Buessinger et al., 2015), explosive (Rejc et al., 2010), ballistic (Padulo et al., 2022) and isometric contractions (Jakobi & Cafarelli, 1998), with evidence suggesting that isometric contractions tend to elicit more consistent BLD effects than dynamic movements (Jakobi & Cafarelli, 1998). While BLD has been widely studied across different movement patterns, research on its manifestation in the upper limbs remains relatively limited, particularly in isometric handgrip tasks. Previous studies have demonstrated BLD during handgrip contractions, but methodological variations - such as differences in seated versus standing postures - may contribute to discrepancies in findings (Cengiz, 2015; Van Dieen et al., 2003). Additionally, individual characteristics such as sex and handedness have been proposed as potential moderators of BLD. Some studies suggest that males exhibit a greater deficit than females (Ye et al., 2019), while others report no significant sex differences (Carr et al., 2021). Similarly, while some evidence indicates that left-handed individuals experience a smaller BLD (Armstrong & Oldham, 1999), other studies suggest that the role of handedness is complex and context-dependent (Cornwell et al., 2012; Škarabot et al., 2016). Given these inconsistencies, further research is needed to clarify the influence of individual characteristics on BLD, particularly regarding upper limb tasks requiring isometric contractions.

The underlying mechanisms of BLD remain unclear, and several hypotheses suggest that psychological, task-related, physiological, and neurophysiological factors could contribute to this phenomenon (see review in (Škarabot et al., 2016)). A key yet understudied aspect of BLD research is the role of task familiarization and motor learning effects. While most studies have investigated BLD in a single testing session (Magnus & Farthing, 2008) or following long-term strength training interventions (Beurskens et al., 2015; Botton et al., 2016; Janzen et al., 2006), fewer have examined how repeated short-term exposure to bilateral tasks may influence its expression. Carr et al. (2021) observed a progressive decrease in BLD across multiple testing sessions, suggesting a potential role for motor learning effects in modulating bilateral force production. Similarly, Secher et al. (1988) reported reductions in the magnitude of the bilateral deficit in the lower limbs after familiarization in both untrained and trained subjects. However, whether these effects are reproducible in resistance-trained individuals performing maximal isometric contractions in upper limb tasks remains unexplored.

Therefore, the present study aimed to examine the presence and evolution of BLD in the upper limbs of resistance-trained individuals during two sessions of maximal isometric handgrip contractions. Specifically, this study sought to determine whether reduced practice of the task in which the presence of BLD is measured modulates its magnitude and whether this effect differs between the dominant and non-dominant hand in both unilateral and bilateral conditions. Additionally, potential sex-related differences in BLD were explored to assess whether biological factors modulate the response to repeated bilateral task exposure. By addressing these questions, this study provides insight into the extent to which task familiarization contributes to changes in bilateral force production in resistance-trained populations.

METHODS

Participants
Thirty-seven young and healthy participants (n = 19 males; age = 23.16 ± 1.89 years; stature = 176.32 ± 6.81 cm; body mass = 80.79 ± 19.32 kg; n = 18 females; age = 23.50 ± 2.41 years; stature = 165.44 ± 5.55; body mass = 57.89 ± 8.65 kg) were recruited voluntarily for this study. Inclusion criteria were an age range of 20 to 30 years and a minimum of one year of resistance training experience. Exclusion criteria were the presence of any musculoskeletal injury that could interfere with performance during testing. Participants were also instructed to refrain from any upper-body strength training for 24 hours prior to each assessment session. All participants were provided with a detailed description of the study and written informed consent was obtained prior to testing. This study conformed to the principles of the Declaration of Helsinki of the World Medical Association (1964) and was approved by the Ethics Committee of the Rey Juan Carlos University (no. 0801202000720).

Study design
The study employed a randomized and crossover design conducted over two experimental sessions separated by 7 days, scheduled at the same time of day for each subject (17:00-20:00 h). The same experimental protocol, which involved both unilateral and bilateral maximal isometric voluntary contraction (MIVC), was used in both sessions. Each participant performed isometric strength assessments using a custom handgrip dynamometer. Each session lasted approximately 45 minutes and was conducted in a controlled laboratory environment. Hand dominance was assessed during the first session using the Edinburgh Handedness Inventory (Oldfield, 1971), revealing that all females and 17 male participants were right-handed, while two males were left-handed.

Isometric strength testing sessions
The assessments were carried out with participants standing, arms extended alongside the trunk. The hands were positioned in a neutral grip (i.e., palms facing each other). Prior to the strength testing, participants were familiarized with the handgrip dynamometer and completed a brief warm-up consisting of three isometric contractions of the handgrip muscles at approximately 25, 50 and 75% of their perceived maximum force (Carr et al., 2021). Two minutes after finishing the warm-up, a MIVC accommodation trial was performed under bilateral condition. Later, participants performed three bilateral MIVCs, three unilateral MIVCs with their dominant hand, and three unilateral MIVCs with their non-dominant hand. Each MIVC lasted 5 seconds, with 1 minute of recovery between trials. The strength measurements were identical across sessions but were performed in a randomized order for each participant: (1) maximal unilateral handgrip contraction of the dominant hand, (2) maximal unilateral handgrip contraction of the non-dominant hand, and (3) maximal bilateral handgrip contraction of both hands. Standardized verbal instructions were provided to the participants before each strength trial to motivate for maximal force production ("*squeeze as fast and as hard as you can in 3, 2, 1, go*").

Materials
Data for the unilateral and bilateral maximal isometric voluntary contractions were measured using custom made hand dynamometers using a commercial strain gauge (NL63, 200 kg; Digitimer) with the distance between handles adjusted to each participant (50% of the distance between the middle fingertip to the metacarpophalangeal flexion crease at the base of the thumb). The force signal was amplified (x484) and sampled (2 kHz) for off-line analysis (Power 1401, Cambridge Electronic Design, United Kingdom; sampling frequency 2 kHz).

Data analysis

For all handgrip contractions (unilateral dominant MIVC, unilateral non-dominant MIVC, bilateral dominant MIVC, and bilateral non-dominant MIVC), the average of the maximum force values from the 3 trials was calculated for each participant. The bilateral deficit was then determined using the bilateral index (BI) formula (Howard & Enoka, 1991):

$$BI\ (\%) = \left(100\ x\ \left(\frac{bilateral}{unilateral\ dominant + unilateral\ \ non - dominant}\right) - 100\right.$$

This formula determines the difference between the force produced in a bilateral condition and the sum of the force produced in unilateral conditions, identifying a bilateral deficit when BI < 0.

Statistical analysis

BI were analysed with a two-way mixed ANOVA with one between-subjects factor (sex), and a within-subject factor of session (1 and 2). In addition, bilateral and unilateral MIVCs also were analysed using a four-way mixed ANOVA with one between-subjects factor (Sex), and three within-subjects factors of Hand (dominant and non-dominant), Session (1 and 2) and Condition (unilateral and bilateral). Post-hoc pairwise comparisons were performed using t-tests with Bonferroni corrections. Effect sizes were presented as partial eta squared (ηp^2), with small effect being 0.01-0.06, medium 0.06-0.14, and large ≥ 0.14 (Cohen, 2013). All data are reported as means ± standard deviations. The normality of the differences was checked using the Shapiro–Wilk test and homogeneity of variances was checked using Levene's test. All statistical analyses were conducted using JASP software (version 0.19.3). The alpha level for statistical difference was set at p = .05.

RESULTS

The mean MIVCs data and BI for both sessions are shown in Table 1.

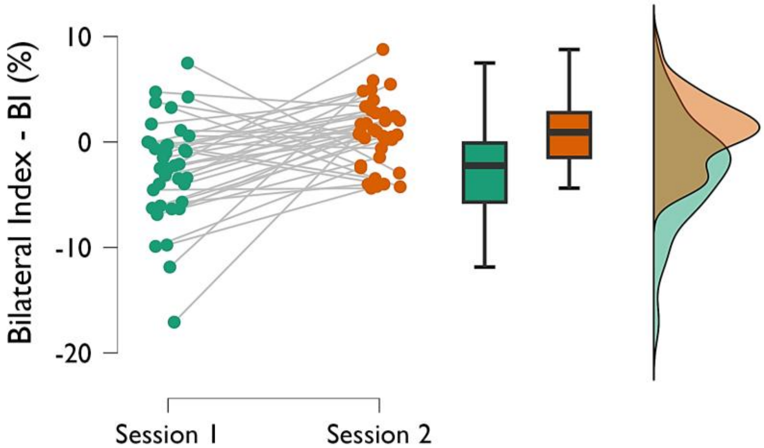
Table 1. Descriptive data (M ± SD) of unilateral and bilateral maximal isometric voluntary contractions and bilateral index for both sessions by sex.

		Male (n = 19) M ± SD		**Female (n = 18) M ± SD**	
		Session 1	Session 2	Session 1	Session 2
Dominant	Unilateral	325.33 ± 65.76	324.77 ± 54.40	217.29 ± 38.06	221.52 ± 33.43
	Bilateral	316.65 ± 64.70	318.30 ± 57.87	206.60 ± 32.45	221.87 ± 39.19
Non-Dominant	Unilateral	289.68 ± 58.48	287.22 ± 59.66	199.94 ± 40.77	193.80 ± 41.12
	Bilateral	287.22 ± 59.66	290.08 ± 59.66	193.80 ± 41.12	203.56 ± 38.03
Bilateral index (%)		- 1.86 ± 3.21	0.65 ± 3.58	- 3.42 ± 6.14	1.04 ± 2.85

Note. M ± SD: Mean ± Standard Deviation. N = Newtons. BI = Bilateral index.

With regard to BI, a two-way mixed ANOVA showed a significant main effect of Session (*F = 12.92, p < .001,* $\eta p^2 = 0.27$), indicating BLD in session 1 (males = - 1.86 ± 3.21; females = - 3.42 ± 6.14) but not in session 2 (males = 0.65 ± 3.58; females = 1.04 ± 2.85) (see Figure 1). However, there was no significant main effect of Sex or interaction between Session × Sex (*p > .05*).

A total of 28 subjects had a BI below 0, and 9 above 0 in the first session. This proportion was practically reversed in the second session, with only 11 subjects having a BI below 0.

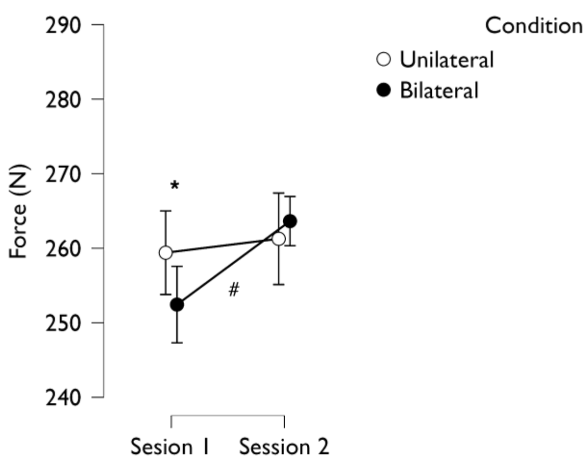


Note. Each dot represents an individual participant, with lines connecting paired values across sessions. Boxplots show the median and interquartile range for each session, and density plots illustrate the distribution of BI values. Negative percentages indicate a bilateral force deficit.

Figure 1. Bilateral index (BI, %) during maximal isometric handgrip contractions in Session 1 and Session 2.

The four-way mixed ANOVA showed significant main effect for Session ($F = 4.38, p < .05, \eta p^2 = 0.11$), Hand ($F = 71.50, p < .001, \eta p^2 = 0.67$), and Sex ($F = 38.87, p < .001, \eta p^2 = 0.53$), whereas no significant effect was found for Condition ($p > .05$). However, these main effects were further qualified by significant interaction effects between Session and Condition ($F = 15.81, p < .001, \eta p^2 = 0.31$), Hand and Sex ($F = 6.92, p < .05, \eta p^2 = 0.17$), and Hand and Condition ($F = 8.11, p < .05, \eta p^2 = 0.19$).

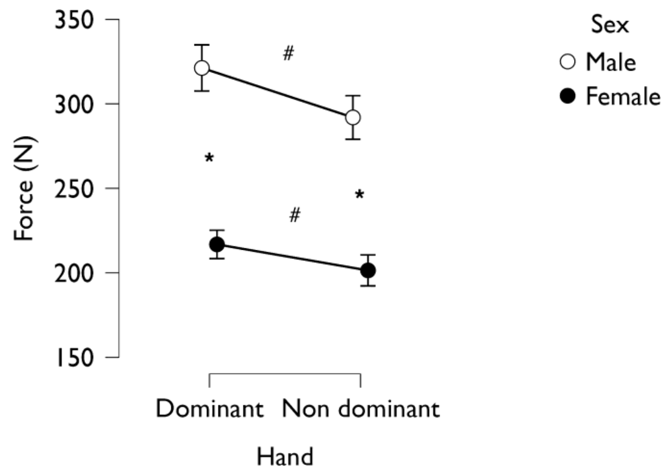
For the Session x Condition interaction, Bonferroni-adjusted post-hoc analyses revealed significant differences between unilateral and bilateral conditions in Session 1 (t = 3.91, d = 0.14, $p < .01$), and between Session 1 and 2 for the bilateral condition only (t = -3.78, d = - 0.23, $p < .01$) (see Figure 2). No other pairwise comparisons reached statistical significance ($p > .05$).



Note. Error bars represent 95% confidence intervals (CI). (*) Indicates statistically significant differences between conditions (p < .05). (#) Indicates statistically significant differences between session 1 and session 2 (p < .05).

Figure 2. Mean and standard deviation force values in Newtons (N) during unilateral and bilateral conditions in both sessions.

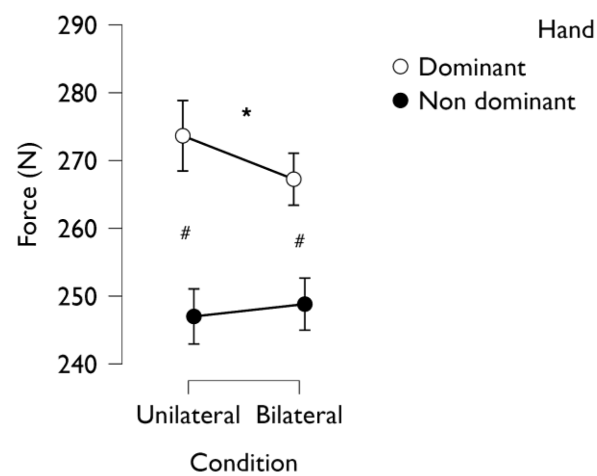
For the Hand x Sex interaction, Bonferroni-adjusted post-hoc analyses showed that dominant hand strength was significantly higher than non-dominant hand strength in both males (t = 7.95, d = 0.59, $p < .001$) and females (t = 4.07, d = 0.31, *p* < .01). In addition, dominant and non-dominant hand strength values in males were significantly higher than in females (t = 6.59, d = 2.09, *p* < .001; t = 5.71, d = 1.82, *p* < .001, respectively). Finally, non-dominant hand strength values for males were significantly higher than dominant hand strength values for females (t = 4.74, d = 1.51, *p* < .001) (see Figure 3).



Note. Error bars represent 95% confidence intervals (CI). (*) Indicates statistically significant differences between males and females (p < .05). (#) Indicates statistically significant differences between dominant and non-dominant hand (p < .05).

Figure 3. Mean and standard deviation values of force in Newtons (N) for males and females in dominant and non-dominant hands.

Regarding the Hand × Condition interaction, Bonferroni-adjusted post hoc analyses revealed that strength values for the dominant hand were significantly higher than those for the non-dominant hand in both unilateral (*t = 7.19, d = 0.53, p < .001*) and bilateral (*t = 8.59, d = 0.37, p < .001*) conditions. In addition, values for dominant hand were also significantly higher in unilateral condition than in bilateral condition (*t = 3.15, d = 0.13, p < .05*), but no significant differences between conditions were observed for non-dominant hand (*p > .05*) (see Figure 4).



Note. Error bars represent 95% confidence intervals (CI). (*) Indicates statistically significant differences between conditions (p < .05). (#) Indicates statistically significant differences between dominant and non-dominant hand (p < .05).

Figure 4. Mean and standard deviation values of force in Newtons (N) in the dominant hand and in the non-dominant hand for unilateral and bilateral conditions.

DISCUSSION

This study aimed to examine the presence and short-term evolution of the BLD during maximal voluntary isometric handgrip contractions across two separate sessions in resistance-trained individuals. By using a no-intervention repeated measures design, we also sought to determine whether the testing sessions themselves could influence the magnitude of BLD. Additionally, we investigated whether the expression of BLD differed between females and males and assessed strength asymmetries between the dominant and non-dominant hand under both unilateral and bilateral conditions, considering potential sex-related differences. The main finding of this study was the presence of BLD in the first session, indicated by BI values below zero (males = -1.86 ± 3.21; females = -3.42 ± 6.14), and the subsequent absence of this phenomenon in the second session, where BI values rose above zero (males = 0.65 ± 3.58; females = 1.04 ± 2.85).

The BLD during the first session ranged from 1.86 to 3.42%, relative lower than previous studies (Carr et al., 2021; Oda & Moritani, 1995), which BLD was 4.98 and 5.2%, respectively. However, whereas most of those studies assessed handgrip strength in a seated position, the current study used a standing posture. These differences in BLD might initially be thought to be due to the role of posture, a factor that has been shown to affect the presence and size of the BLD. Turnes et al. (2022) observed a more pronounced BLD in the standing versus seated position during a handgrip tasks. In addition, it has been suggested that postural stability plays a critical role in BLD expression, as standing tasks impose greater postural demands that may influence force production and neuromuscular coordination (Pelayo-Tejo et al., 2024). However, according to these studies, we should have found higher BLD values than those reported in the sitting position. Therefore, it is unlikely that these differences are due to posture requirements. Other factors, such as subject characteristics, measuring instruments, or rest duration, could contribute to the different BLD range between studies. It is important to highlight that the participants in our study were resistance-trained individuals familiar with both unilateral and bilateral exercises, although not with the task being tested. The presence of BLD during the first session suggests that general training experience is not enough to abolish this phenomenon.

The absence of BLD in the second session indicates that short-term task practice can significantly modulate bilateral force production. This result aligns with prior findings indicating that short-term exposure to a specific motor task could improve force coordination and neuromuscular efficiency (Secher et al., 1988). In addition, the role of cognitive engagement should not be overlooked, as motor learning through repetition has been shown to optimize force distribution in bilateral tasks (Farthing et al., 2009). Therefore, it is worth considering whether bilateral grip strength deficit is a relevant phenomenon from a training and rehabilitation perspective or, on the contrary, a futile phenomenon resulting from insufficient practice in the task being assessed. In any case, methodologically, this study highlights the importance of conducting at least two sessions of bilateral grip deficit assessment to explore the presence or absence of this phenomenon.

Sex-related differences in BLD were not observed, consistent with previous research suggesting that both males and females experience similar BLD during handgrip contractions (Carr et al., 2021). As expected, males exhibited greater absolute force output than females in both unilateral and bilateral conditions, in line with established sex differences in upper limb strength (Ye et al., 2019). In our study the hand dominance was not a factor affecting the BLD, with greater strength in the dominant than in non-dominant hand independent of whether the contraction was performed unilaterally or bilaterally. The greater strength demonstrated by the dominant hand is in line with a recent meta-analysis of 87 scientific studies (Foley et al., 2025). The effect of hand dominance on bilateral deficits is inconclusive. Initially, it was suggested that the bilateral deficit is due to force reduction in the dominant limb (Henry & Smith, 1961). However, the only study that assessed bilateral deficits, considering handedness and laterality, only observed bilateral deficits in the left-handed group (Cornwell et al., 2012). Our study does not support these results, given that our sample consisted of right-handed individuals, except for two subjects. Further studies, including laterality and handedness, are needed to evaluate their role in bilateral deficits.

This study has several limitations. First, we only measured bilateral grip deficits. We selected this action based on Simoneau-Buessinger et al. (2015), who proposed that handgrip exercises minimize the influence of postural stability, providing a more isolated model for assessing bilateral force production mechanisms. Therefore, we do not know whether our results can be extrapolated to other types of contractions involving different muscle groups. Second, we only explored bilateral grip deficits in two sessions, so we lack data to evaluate the effect of practice across multiple testing sessions.

CONCLUSIONS

In conclusion, our study with strength-trained subjects indicates the presence of a bilateral grip deficit in the first assessment session but not in the second. Sex and handedness dominance did not affect this deficit, but the specific practice of the assessed task did. Our results suggest the need to practice the task being assessed to objectively measure this deficit. This could be relevant from a methodological perspective in the study of this phenomenon.

AUTHOR CONTRIBUTIONS

Conceptualization: Miguel Fernández-del-Olmo, Antonio Luque-Casado. Methodology: Miguel Fernández-del-Olmo. Data collection: Elvira Molinero-Martín, Víctor López-Zarraute. Data curation and formal analysis: Elvira Molinero-Martín, Miguel Fernández-del-Olmo. Writing–original draft: Elvira Molinero-Martín, Víctor López-Zarraute, Antonio Luque-Casado. Writing–review & editing: Elvira Molinero-Martín, Miguel Fernández-del-Olmo, Antonio Luque-Casado, Víctor López-Zarraute. Project administration: Miguel Fernández-del-Olmo, Antonio Luque-Casado.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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