

# GENDER AND LIMB EFFECTS ON ADULT NORMATIVE DATA FOR THE BIODEX BALANCE SYSTEM

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## Abstract:

Posturography normative data in healthy populations is crucial for several reasons including monitoring the independence issues related to activities of daily living (ADLs), fall and incapacity avoidance, and residual injury impairment. The Biodex Balance System requires updated normative data regarding healthy persons because of recent revisions to the Biodex Balance System. Further, this study aimed to determine and compare gender and limb performance in 161 adults aged 18-55 years ( $n = 80$  males;  $n = 81$  females). Assessments involved both static and dynamic stability tests such as double-leg and single-leg balance tests at platform stability which served as outcome measurements. Females performed significantly ( $p \leq .05$ ) better on double-leg static balance ( $p = .031$ ), double-leg dynamic balance ( $p = .002$ ), and single-leg dynamic balance on both the left ( $p = .003$ ) and right legs ( $p = .013$ ) when compared to males. The normative values and findings of this study not only enable the evaluation of individual performance regarding the balance of adults but also suggest the need to use gender-stratified normative data when using the Biodex Balance System to interpret double- and single-leg, static and dynamic balance test performance.

**Key words:** postural balance, posturography, health, reference values

## Introduction

Postural balance is not only an important motor ability for activities of daily living (ADL) (Halvansson, Dohrn, & Stähle, 2015) but is critical to avoid falls and incapacities (Fourie, et al., 2012; Mancini & Horak, 2010). It is for this reason that double- and single-leg stance postural stability testing and training form integral components of sports medicine testing and rehabilitation (Mancini & Horak, 2010; Shariat, et al., 2022). Both double- and single-leg stance postural stability testing appear to be suggestive of not only residual injury impairment, but also of future injury risk (Bahari, Naghdi, Sheikh, & Shaw, 2021; Mancini & Horak, 2010; McKeon & Hertel, 2008).

That is why numerous field tests, such as the Berg Balance Scale, and laboratory-based tests, particularly the Biodex Balance System, are commonly used in clinical settings. However, little evidence exists for the reliability and validity of such tests (Mancini & Horak, 2010). Concurrently, such tests are affected by various factors, such as age, gender, and other body characteristics that require specific reference values (Andreeva,

et al., 2020). This allows the elimination of the contradicting research evidence of such field tests and clinically appropriate comparisons. Nevertheless, existing research shows gender differences in balance abilities (Chang & Do, 2015; Dallinga, Van Der Does, Benjaminse, & Lemmink, 2016; Muraki, et al., 2013), while some studies do not (Melam, Buragadda, Alhusaini, Ibrahim, & Kachanathu, 2014; Riva, et al., 2013). Therefore, the objective of this study was to establish and update normative data regarding healthy persons for the Biodex Balance System and to compare gender and limb performance.

## Methods

### Sample

The sample of participants in this cross-sectional design was selected from communities in the city of Johannesburg, South Africa. The sample was composed of 161 apparently healthy ( $n = 81$  females;  $n = 80$  males) apparently healthy adults aged between 18-55 years. Participants were excluded if they were obese ( $BMI > 30 \text{ kg.m}^{-2}$ ) (Son,

2016), same family (parents or siblings to eliminate over-representation from a single family or household and eliminate bias) (Sajjadi & Paparella, 2008), or continuously active in competitive sport prior and upon the date of data collection (Zemková, 2014).

To further ensure the reliability and validity of the study, participants with diagnosed medical problems, either acute or chronic conditions, particularly neurological disorders (i.e., Meniere’s disease, middle ear infection) (D’Silva, Lin, Staecker, Whitney, & Kluding, 2016; Meldrum, et al., 2012), pregnancy (Segal & Chu, 2015), or if taking any medication or drug substances that could potentially affect the results (De Groot, et al., 2013; Mahmoudzadeh, et al., 2020) were excluded from this study.

Prior to the commencement of the study, written informed consent was obtained from all participants to engage in the study. This study was approved by the Institutional Review Board of the University of Johannesburg (REC-01-123-2016).

**Data collection**

During data collection, initially, participants were assessed using a self-reported leg dominance questionnaire (van Melick, et al., 2017). This implies that participants had to identify the leg which is mostly utilised when kicking the ball to a maximum distance (Mahmoudzadeh, et al., 2021). The pre-programmed “Postural Stability Test” on the Biodex Balance System (Model 950-440, Biodex Medical Systems, Inc., Shirley, New York) was used to assess both static and dynamic balance (Cachupe, Shifflett, Kahanov, & Wughalter, 2001; Karimi, Ebrahimi, Kahrizi, & Torkaman, 2008; Parraca, et al., 2011). Balance ability was assessed using four different evidence-based protocols: (1) double-leg stable/static (level 12), (2) double-leg unstable/dynamic (level 8), (3) dominant and non-dominant, single-leg stable/static (level 12), and (4) dominant and non-dominant, single-leg unstable/dynamic (level 8) (Finn, Alvarex, Jett, Axtell, & Kemler, 1999). Foot placement was prescribed by the system’s software according to each participant’s height. Participants were provided three chances with one trial for familiarisation with the device and the test procedures prior to testing. The average score between

the last two trials was recorded as the final score. The “Overall Stability Index” score was recorded as anterior-posterior, as well as left-to-right perturbations (Biodex Medical Systems, 2000). Previously, overall composite scores (intraclass correlation coefficients [ICC] ICC3,1 = 0.71, and minimal detectable change [MDC] = 1.21) have been found for the Biodex system showing moderate test-retest reliability. In addition, the Biodex overall Sway Index (SI) has previously shown acceptable reliability criterion validity (r = 0.52) (Peller, et al., 2023).

**Statistical analysis**

Descriptive statistics of the variables were presented as means±standard deviations and percentiles. Due to the heterogeneousness of the data, the Kruskal-Wallis and Mann-Whitney U tests were used to test for significant differences in balance abilities between males and females. The significance level was set at p≤.05. Statistical analyses were performed using the Statistical Package for the Social Sciences ver. 26.0 (IBM Co., Armonk, NY, USA).

**Results**

Out of the 161 participants, only five were left-dominant (3.11%), with 156 being right-dominant (96.89%). While no significant differences were found in BMI between males and females (p=.296); however, males (n = 80) were reported as significantly older (p=.000), taller (p=.000), and heavier (p=.000) than females (n = 81) (Table 1).

Tables 2 and 3 present gender- and limb-specific normative data for healthy adults for the Biodex Balance System. Practically, these reference percentile values provide needed comparative data for sports medicine practitioners who use the Biodex Balance System in healthy adults.

Interestingly, females scored significantly better in double-leg static balance (p=.031) and double-leg dynamic balance (p=.002) when compared to males (Table 4). Moreover, females demonstrated a significantly better single-leg dynamic balance on both the left (p=.003) and right lower limbs (p=.013).

Table 1. Demographic characteristics of participants in each group

Variable	Females (n = 81)	Males (n = 80)	Significance (p-value)
Age (years)	32.86 ± 12.14	34.64 ± 11.12	.000*
Height (cm)	163.69 ± 5.51	175.25 ± 8.01	.000*
Body weight (kg)	64.16 ± 10.37	78.73 ± 10.36	.000*
BMI (kg.m <sup>-2</sup> )	23.90 ± 3.45	25.61 ± 2.78	.296

Note. Data reported as means±standard deviations (SD). \*: Statistically significant (p≤.05). cm: centimetres; kg: kilograms; BMI: body mass index; kg.m<sup>-2</sup>: kilograms per square metre. \*Males (n = 80) were reported as significantly older (p=.000), taller (p=.000), and heavier (p=.000) than females (n = 81).

Table 2. Limb-specific normative data for healthy females for the Biodex Balance System

Percentile	10	20	30	40	50	60	70	80	90
<b>Stable conditions</b>									
Double-leg stable	.200	.200	.300	.300	.400	.400	.400	.500	.600
Single-leg stable (left)	.600	.700	.800	.800	1.000	1.020	1.200	1.460	2.080
Single-leg stable (right)	.600	.700	.800	.800	.900	1.100	1.200	1.400	1.800
<b>Unstable conditions</b>									
Double-leg unstable	.400	.500	.500	.600	.600	.700	.800	.800	.900
Single-leg unstable (left)	.500	.600	.700	.800	.900	1.000	1.100	1.200	1.300
Single-leg unstable (right)	.500	.600	.700	.800	.900	1.000	1.100	1.200	1.400

Table 3. Limb-specific normative data for healthy males for the Biodex Balance System

Percentile	10	20	30	40	50	60	70	80	90
<b>Stable conditions</b>									
Double-leg stable	.200	.300	.330	.400	.400	.500	.500	.600	.700
Single-leg stable (left)	.600	.620	.700	.800	.900	.900	1.000	1.200	1.500
Single-leg stable (right)	.600	.700	.700	.800	.900	1.000	1.100	1.200	1.400
<b>Unstable conditions</b>									
Double-leg unstable	.500	.520	.600	.700	.800	.800	.900	.980	1.000
Single-leg unstable (left)	.700	.700	.800	.900	1.000	1.160	1.300	1.400	1.500
Single-leg unstable (right)	.600	.800	.830	.900	1.000	1.100	1.200	1.300	1.400

Table 4. Gender and limb effects on adult normative data for the Biodex Balance System

Parameter	Females (n = 81)	Males (n = 80)	Significance (p-value)
<b>Stable conditions</b>			
Double-leg stable	0.415 ± 0.24	0.473 ± 0.27	.031*
Single-leg stable (left)	1.159 ± 0.67	0.969 ± 0.45	.088
Single-leg stable (right)	1.111 ± 0.63	0.956 ± 0.42	.136
<b>Unstable conditions</b>			
Double-leg unstable	0.660 ± 0.23	0.765 ± 0.23	.002*
Single-leg unstable (left)	0.893 ± 0.33	1.069 ± 0.35	.003*
Single-leg unstable (right)	0.916 ± 0.35	1.051 ± 0.36	.013*

Note. Data reported as means±standard deviations (SD). \*: Statistically significant (p≤.05.)

### Discussion and conclusions

Although there are studies in the literature that provide reference data for balance performance, research is limited regarding gender-specific normative data, especially for the Biodex Balance System. Further, much data focused on existing conditions but failed to investigate healthy adults with an aim to the prevention of conditions and/or injuries related to poor balance. This dearth of reference data is especially apparent for specific limbs during static and dynamic conditions. The results of this study present updated normative data for the Biodex Balance System regarding healthy persons necessitated by recent revisions to the Biodex Balance System (Riemann & Davies, 2013). In addition

to this reference data, the present study also demonstrates that healthy females performed better on double-leg static balance, double-leg dynamic balance, and single-leg dynamic balance on both the left and right legs when compared to males indicating the need to use gender-stratified normative data when using the Biodex Balance System to interpret double- and single-leg, static and dynamic balance test performance.

While some research suggests that no differences exist in static balance between males and females (Melam, et al., 2014; Riva, et al., 2013), the present study supports those findings that females perform better than males on static balance tests (Dorneles, Pranke, & Mota 2013; Howell, Hanson,

Sugimoto, Stracciolini, & Meehan, 2017). However, it must be noted that in this study, males and females performed equally on static single-leg balance. As such, this study's findings support the proposition that females tend to have a lower postural sway than males, therefore allowing them to have better postural control and balance than males (Dorneles, et al., 2013). It may be that the methodological differences, such as the variety of instrumentation, design, and populations used, may explain the mixed results reported. Despite this, these findings add to existing knowledge in that both the older and revised versions of the Biodex Systems, investigations are conspicuous in their absence when considering gender differences, especially in single-leg balance performance (Riemann & Davies, 2013).

Possible reasons for this increased balance performance in females can be explained by the inverted pendulum model of balance and may relate to them having a lower centre of mass and thus a lower centre of gravity, especially under more challenging unstable conditions (Schulleri, Johannsen, Michel, & Lee, 2022). Specifically, females have a lower height effectively reducing their centre of gravity when compared to their male counterparts (Alonso, et al., 2015; Alter, 2004; Rivas & Andries, 2007). Further, not only do females have a reduced centre of gravity, but this lowered centre is supported by a larger pelvis, allowing for a greater relative distance between the two femoral heads, thus increasing the relative width of the base of support (Rivas & Andries, 2007). Specifically, the reduction in the male's base of support, especially during single-leg balance testing results in frequent compensatory movements (Riemann & Davies, 2013).

Another gender-specific anthropometric factor that could affect balance relates to trunk-cephalic length, especially during upright stance. In this regard, the longer torsos and broader shoulders of males increase the amount of postural sway (Alonso, Brech, Bourquin, & Greve, 2011). In addition, the

increased mass of males, when compared to females, also leads to increased postural instability (Greve, Cug, Dulgeroglu, Brech, & Alonso, 2013; Hue, et al., 2007). Of particular importance for postural testing, and especially postural training, is those taller individuals, whether male or female, may require additional gastrocnemius muscular fitness (i.e., flexibility, strength, and muscle endurance, etc.) training, since gastrocnemius muscle activity is found to be increased in taller individuals during standing, while ankle stiffness is inversely related to balance performance (Alonso, et al, 2011, 2015).

Several other explanations for differences in gender balance performance have been suggested, such as differences in male and female activity (Thomas & French, 1985). However, this study did not include the levels of physical or athletic activity as part of the inclusion criteria. It is for this reason that further investigation is necessitated to determine the mechanisms responsible for differences in male and female balance performance on the Biodex Balance System, to fully interpret balance test scores.

Compared with the limb differences, the results of this investigation revealed compelling gender-specific differences when assessing balance using the Biodex Balance System in healthy adults. Posturography normative data in this population is crucial for the surveillance of postural balance and for the timely diagnosis of any dysfunction. We provide gender- and limb-based normative values for the Biodex Balance System, which will likely be helpful when using this technology to determine individual capabilities that could help athletes and coaches identify areas in need of improvement and can be used in goal setting (Semin, et al., 2008). This data could also be used to identify lower percentiles that can be used as a "warning signal" to conduct additional tests to identify possible independence issues related to ADLs, fall and incapacity avoidance, residual injury impairment, and future injury risk in sports medicine testing and rehabilitation.

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