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Does the 2d:4d ratio present a relationship with static strength indicators in elite paralympic powerlifting?

Presenta la relación 2d: ¿4d una relación con los indicadores de fuerza estática en el levantamiento de pesas paralímpico de élite?

*Abílio Manoel do Nascimento Rodrigues, *Felipe J. Aidar, *Márcio Getirana-Mota, **Túlio Banja, ***Georgian Badicu, ****, ***** Hadi Nobari, *Jymmys Lopes dos Santos, ******Paulo Francisco de Almeida-Neto, ******Breno Guilherme de Araújo Tinoco Cabral, ********Nuno Domingos Garrido, *Taísa Pereira Santos, *Rapahel Fabrício de Souza, *******Victor Machado Reis, ********Ciro José Brito, *Lucio Marques Vieira-Souza

*Federal University of Sergipe (Brazil), **Federal University of Ceará (Brazil), ***Transilvania University of Brasov (Romania), ****University of Mo-haghegh Ardabili (Iran), *****University of Extremadura (Spain), ******Federal University of Rio Grande do Norte (Brazil), *******University of Trás-os-Montes e Alto Douro (Portugal), ********Federal University of Juiz de Fora (Brazil)

Abstract. Background: Paralympic Powerlifting is a strength sport. On the other hand, the relationship between force indicators and the ratio of the lengths of the second and fourth fingers of the hand (D2:D4) has been investigated. Objectives: To evaluate the relationship of the D2:D4 finger length ratio with performance in Paralympic Powerlifting. Methodology: Thirteen elite Paralympic Powerlifting athletes were evaluated for static force indicators, Rate of Force Development (RFD), Maximum Isometric Force (MIF), Impulse, Variability, and Time to MIF. The D2:D4 ratios were measured, and correlations were made between the various possibilities of D2:D4 ratios and static force indicators. Results: Moderate correlations were found between RFD and Left D4 ("r" = 0.569) and between Variability and R-L D2:D4 Difference. ("r" = 0.570). However, no correlation was found between D2:D4 ratios and static force indicators in Paralympic Powerlifting athletes for the other variables. Conclusion: The D2:D4 ratio does not seem to be a reliable predictor of static force indicators in Paralympic Powerlifting athletes.
Keywords: Performance predictor, Prenatal testosterone, Paralympic Powerlifting

Resumen. Antecedentes: el levantamiento de pesas paralímpico es un deporte de fuerza. Por otro lado, se ha investigado la relación entre los indicadores de fuerza y la relación entre las longitudes del segundo y cuarto dedo de la mano (D2:D4). Objetivos: Evaluar la relación de la relación de longitud de los dedos D2:D4 con el rendimiento en levantamiento de pesas paralímpico. Metodología: Trece atletas de levantamiento de pesas paralímpico de élite fueron evaluados en cuanto a indicadores de fuerza estática, tasa de desarrollo de fuerza (RFD), fuerza isométrica máxima (MIF), impulso, variabilidad y tiempo hasta MIF. Se midieron las relaciones D2:D4 y se hicieron correlaciones entre las diversas posibilidades de relaciones D2:D4 y los indicadores de fuerza estática. Resultados: Se encontraron correlaciones moderadas entre RFD y Left D4 ("r" = 0,569) y entre Variabilidad y R-L D2:D4 Diferencia. ("r" = 0,570). Sin embargo, no se encontró correlación entre las proporciones D2:D4 y los indicadores de fuerza estática en atletas de levantamiento de pesas paralímpicos para las otras variables. Conclusión: La relación D2:D4 no parece ser un predictor confiable de los indicadores de fuerza estática en atletas de Powerlifting Paralímpico.
Palabras clave: predictor de rendimiento, testosterona prenatal, levantamiento de pesas paralímpico

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Márcio Getirana-Mota
marcio_getirana@hotmail.com

Introduction

The practice of strength sports has become increasingly popular worldwide (Albrecht et al., 2023), and special groups, people with disabilities and olders (Aidar et al., 2012, 2018; DE Matos et al., 2017; Mazini Filho et al., 2018). Among the most practiced strength activities, gym activities and powerlifting stand out, both in conventional and Paralympic modalities (Aidar, Clemente, de Lima, et al., 2021; Fonseca et al., 2020; D. van den Hoek et al., 2023; D. J. van den Hoek et al., 2022).

In addition to the training itself, several studies have investigated the possible influences of strength training on anthropometric issues (Adami et al., 2022; Ferrari et al., 2022; Reya et al., 2021), and physiological aspects (Hackett et al., 2020), especially in conventional and Paralympic powerlifting (Aidar, Fraga, et al., 2021; de Aquino Resende et al., 2021; Mendonça et al., 2021; Puce et al., 2022). It was observed that Paralympic athletes tend to present greater muscular strength compared to conventional athletes (D. van den Hoek et al., 2023; D. J. van den Hoek et al., 2022).

The relationship between muscular strength and various factors, including hormonal factors and testosterone levels, has been widely studied (Landram et al., 2020; Sönksen et al., 2018; Wilk et al., 2018). That is, the 2D:4D digit ratio has been proposed as a marker of prenatal testosterone exposure and also of the testosterone-estradiol ratio. Digit ratio is measured by dividing the length of the index finger (2D) by the ring finger (4D), this ratio is reported to be an indicator of prenatal testosterone and estrogen (Manning, Scutt, Wilson & Lewis-Jones., 1998), indicating that a low

2D:4D ratio indicates high prenatal testosterone exposure and low prenatal estrogen exposure. Otherwise, it means there was low exposure to testosterone and high exposure to estrogen (Manning, Scutt, Wilson & Lewis-Jones., 1998). It is already known that there is a positive or negative correlation between the 2D:4D ratio and muscle strength depending on sex (Hisasue et al., 2012; Hönekopp & Watson, 2010; Knickmeyer et al., 2011; Lutchmaya et al., 2004, 2004; Malas et al., 2006; Manning, Scutt, Wilson & Lewis-Jones., 1998; Manning, 2011; Ventura et al., 2013).

Although some research has investigated the relationship between the 2D:4D ratio and performance in different sports (Koç et al., 2017; Nobari, Alves, et al., 2021), and some studies have shown a negative correlation of the D2:D4 ratio with sports performance (Frick et al., 2017; Hönekopp & Watson, 2010; Hull et al., 2015), and others have shown a positive relationship between D2:D4 and performance (Bennett et al., 2010; Jürimäe et al., 2008; Longman et al., 2011). However, the study of people with disabilities and athletes remains unclear, considering that adolescence tends to present changes and this population tends to have its normal development altered and its performance capacity in strength sports can be predicted by the 2D:4D proportion. (Nobari, Alves, et al., 2021; Nobari, Vahabidelshad, et al., 2021).

Thus, the proposal of our study was to evaluate the relationship of the D2:D4 finger length ratio and its relationship with performance in Paralympic powerlifting. We hypothesized that there is a positive relationship between the 2D:4D ratio and performance in paralympic powerlifting.

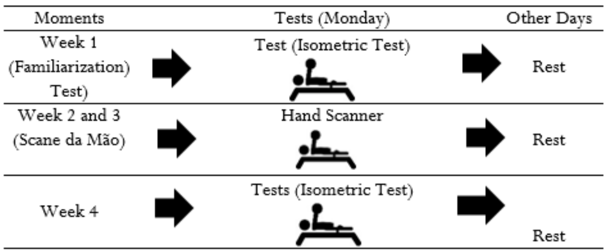

Figure 1. Experimental study design.

Methodology

Study design

All procedures were carried out at the same time (9:00 AM to 12:00 PM) for each athlete in similar conditions (between 22° and 25°C air temperature and ~60% relative air humidity) in a weightlifting room at the Federal University of Sergipe. In the first week, the evaluated subjects underwent a familiarization session. From the second week, collections were made between 9:00 AM and 12:00 PM, according to the subjects' availability. The second and fourth weeks were dedicated to scanning the athletes' hands, and the third week was designated for collecting static force indicators. Participants were familiarized with the tests, procedures and rested for at least 48 hours before the evaluations. They were instructed to maintain the same routines during the evaluation days, avoiding strenuous exercises and refraining from consuming caffeine 48 hours before the test (Figure 1). This study is characterized as an exploratory study with quantitative data analysis.

Sample

The sample for this study was made up of convenience with 13 male individuals aged between 18 and 35 years. The athletes had more than 24 months of experience in Paralympic Powerlifting (PP) training, with competitive experience at national level, all eligible for the modality (IPC, 2023) and ranked among the top ten in their respective categories. Six athletes had malformations in the lower limbs (arthrogryposis), two had sequelae of polio, four had amputations and one had a spinal cord injury (below T8) by accident. High to very high correlations have been reported between physical fitness and training load, and their 2D:4D ratio (Lombardo et al., 2020; Mendonça et al., 2021; Nobari et al., 2020).

High to very high correlations have been pointed out between physical fitness and training load, and their 2D:4D ratio(Lombardo et al., 2020; Mendonça et al., 2021; Nobari et al., 2020).

The G-Power software (University of Dusseldorf, Dusseldorf, Germany) was used to obtain the statistical population calculation. The model used was a priori considered in accordance with the main objective of the study: t-tests-Correlation: point biserial model. (Cohen, 1988, 1992). The results served as the basis for determining the sample size with a power greater than 80%. The variables considered were: two-tailed, α error < 0.05 and very large effect size.

All participants were volunteers and signed the informed consent form according to the Resolution 466/2012 of the National Ethics Committee in Research (CONEP) of the National Health Council (CNS). We also followed the ethical principles expressed in the Helsinki Declaration (1964, revised in 2013) of the World Medical Association. This study was approved by the Ethics Committee in Research of the Federal University of Sergipe, protocol number CAAE: 2.637.882 (approval date: May 7, 2018). The sample characteristics are displayed in Table 1.

Table 1.
Characterization of subjects.

Variables	Values
Age (years)	29.69 ± 6.49
Body Weight (Kg)	80.62 ± 21.82
Experience (years)	4.37 ± 0.37
Footprint Width (cm)	58.47 ± 15.71
1RM Bench Press Test (Kg)	143.69 ± 43.26 *
1RM/Body Weight	1.83 ± 0.45 **

* All athletes with loads that keep them in the top 10 of their national categories.
** Bench press values above 1.4 would be considered elite athletes(Ball & Weidman, 2018).

Instruments

The body mass of the athletes was evaluated on a platform-type wheelchair digital scale (Micheletti, São Paulo, Brazil) in the sitting position. The scale with a maximum capacity of 300 kg and with a size of 1.50 m by 1.50 m. The flat bench press was performed on an official bench (2.10 m long, Eleiko, Halmstad, Sweden) and an Olympic barbell (total length 220 cm, weight 20 kg), in accordance with the International Paralympic Committee (IPC, 2022).

Isometric force evaluation

The measurement of muscular strength, rate of force development (RFD), maximal isometric force (MIF), impulse, variability, and time to maximum force (Time) (m/s), were determined using a Chronojump (Chronojump, Boscosystem, Barcelona, Spain), with a capacity of 500 kg, output impedance of 350 ± 3ohm, insulation resistance greater than 2000 cc, input impedance of 365 ± 5 ohms, 24-bit analog-to-digital converter, and 80 Hz. The equipment was attached to the bench press using a Spider HMS Simond carabiner (Simond, Chamonix, France), with a breaking load of 21KN, approved for climbing by the regulatory agency Union International des Associations d'Alpinisme (UIAA). A steel chain with a breaking load of 2,300 kg was used to attach the load cell to the bench. Maximum isometric force (MIF) was measured as the maximum force generated by the upper limb muscles during the adapted bench press exercise (IPC, 2018). MIF was determined in Newtons (N) using the formula N = (M) x (C), where M = mass in kg and C = 9.80665, measured between the attachment point of the load cell and the adapted bench press, which was adjusted to allow for an elbow angle close to 90°, and at a distance of 15cm from the starting point (chest to bar), checked with an angular range of motion measuring device, model FL6010 (Sanny, São Bernardo do Campo, SP, Brasil) (Aidar, Clemente, Matos, et al., 2021; Blazevich et al., 2020; Buckthorpe & Roi, 2018; Maestroni et al., 2020; Milner-Brown et al., 1986; Resende et al., 2020; Rodríguez-Rosell et al., 2018)(Figure 2).

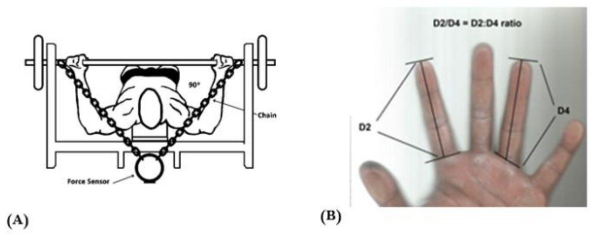

Figure 2. Demonstration of the positioning of the force sensor for evaluation of static force indicators (A), and o modelo da proporção D2:D4 (B).

Participants were instructed to perform a maximum effort to extend their elbows (as quickly as possible) and then relax to evaluate MIF. The rate of force development (RFD) was determined by the ratio of force and time to reach maximum force (RFD = ΔForce / ΔTime). In addition, the time interval to reach MIF was determined over time. (Aidar, Clemente, Matos, et al., 2021; McGuigan & Winchester, 2008; Soares Freitas Sampaio et al., 2020; Teles et al., 2021).

Finger measurements

The measurement of the length of the 2D and 4D fingers followed a previous protocol (Manning, Scutt, Wilson & Lewis-Jones., 1998). The athletes were instructed to place their right and left palms on the scanner, with their fingers spaced approximately 2.0 cm apart. The hand image captured by the scanner was transferred to Kinovea software version 0.9.5 (Free Software Foundation Inc., Boston, Massachusetts, USA) used to measure finger length.

The length of the 2D and 4D fingers was measured from the proximal phalanx (flexion) to the distal phalanx. The proportion of the fingers was realized with the division of 2D:4D. A Brother Scanner (Brother Industries, Nagoya, Japan) with a measurement accuracy of 0.01 cm was used to measure the length of the second and fourth finger up to the fingertip. The difference between the right finger ratio 2D:4D (RF2D:4D) and the left finger ratio 2D:4D (LF2D:4D) was calculated (Bennett et al., 2010; Nobari, Alves, et al., 2021). The evaluations were performed by the same assessor, and intra-observer reliability was assessed twice, with one week apart. The intraclass correlation coefficient (ICC) for the 2D:4D ratio was 0.96 and 0.98. Figure 3 shows an example of the capture and measurement of finger length.

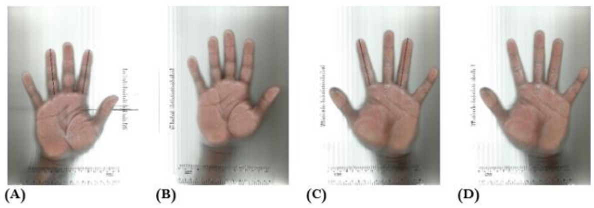

Figure 3. Representative hand scanner with markings

Pocedures

To assess MIF, RFD, Impulse, Variability and Time to MIF, athletes were instructed to perform a maximum movement looking for elbow extension (as fast as possible). The test was performed and the participants maintained the maximum contraction for 5.0 seconds. The RFD was determined by the force-time relationship until reaching the maximum force (Aidar, Clemente, Matos, et al., 2021; McGuigan & Winchester, 2008; Resende et al., 2020).

Statistics

Descriptive statistics were performed using measures of central tendency, mean ± standard deviation (SD), and 95% confidence interval (CI). The Shapiro-Wilk test was used to verify the normality of the variables, taking into account the sample size. the data met normality and was used the correlation Pearson (r) were defined as > 0.1 = trivial; 0.1 > 0.3 = small; 0.3 > 0.5 = moderate; 0.5 > 0.7 = large; 0.7 > 0.9 = very large; and > 0.9 = almost perfect (Hopkins et al., 2009). Consequently, linear regression was used to predict the aforementioned variables with LF2D:4D and RF2D:4D, due to the high correlation results obtained.

Statistical analyses were performed using the computerized Statistical Package for the Social Sciences (SPSS 25.0) (IBM, New York, USA).

Results

It was observed that there was no significant correlation between 2D:4D for any indicator of right hand strength. There was a moderate correlation between the left fourth digit (4D) and the RFD with a coefficient of determination of 0.32% (R2) and a moderate correlation between the 2D:4D difference (R-L) and the variability (0.32% R2) (table 3).

Table 2 shows the descriptive values of finger length and their respective ratios, as well as the static force indicators.

Table 2.
Values of D2:D4 ratios and static force indicators.

Variables	Values
Right Second	7.55±0.51
Right Fouth	8.00±0.52
Right D2:D4	0.94±0.03
Left Second	7.56±0.42
Feft Fourth	7.94±0.61
Left 2D:4D	0.95±0.04
Right-Left 2D:4D Difference	-0.01±0.04
MIF (N)	875.32±223.81
RFD (N/s)	4135.74±3291.33
Impulse (N.s)	3688.91±1088.32
Variability (%)	1.40±1.04
Time at MIF (ms)	2636.33±1434.40

2D: Length of the second finger; 4D: Length of the fourth finger; MIF: Maximum Isometric Force; RFD: Rate of Force Development.

In table 3, the results of the correlations between finger ratios and force indicators are presented.

Table 3.
Correlation between various finger length ratios and static force indicators.

Variable	Right Second	Right Fourth	Right 2D:4D	Left Second	Left Fourth	Left 2D:4D	R-L 2D:4D Difference	MIF (N)	RFD (N/s)	Impulse (n.s)	Variability %	Time MIF (ms)
Right Second	1.00											
p	0											
R^2												
Right Fourth	0.720*	1.00										
P	0.006											
R^2	0.52											
Right 2D:4D	0.374	0.186	1.00									
p	0.208	0.544	0									
R^2												
Left Second	0.704*	0.861*	0.132	1.000								
p	0.007	<0.001	0.668	0								
R^2	0.48	0.74										
Left Fourth	0.594&	0.919#	0.388	0.752*	1.000							
p	0.032	<0.001	0.190	0.003	0							
R^2	0.35	0.84		0.56								
Left 2D:4D	0.313	0.476	0.462	0.202	0.734*	1.00						
p	0.298	0.100	0.112	0.508	0.004	0						
R^2					0.54							
R-L 2D:4D Difference	0.736*	0.434	0.363	0.187	0.479	0.622&	1.00					
p	0.004	0.138	0.223	0.541	0.098	0.023	0					
R^2	0.54					0.39						
MIF (N)	0.165	0.093	0.230	0.366	0.179	0.089	0.077	1.00				
p	0.590	0.762	0.450	0.219	0.559	0.774	0.803	0				
R^2												
RFD (N/s)	0.544	0.462	0.014	0.448	0.569&	0.512	0.462	0.621&	1.00			
p	0.055	0.112	0.964	0.124	0.042	0.074	0.112	0.024	0			
R^2					0.32			0.38				
Impulse (N.s)	0.302	0.132	0.202	0.429	0.223	0.191	0.038	0.654&	0.527	1.00		
p	0.316	0.668	0.508	0.143	0.143	0.532	0.901	0.015	0.064	0		
R^2								0.43				
Variability %	0.256	0.140	0.406	0.048	0.208	0.262	0.570&	0.022	0.342	0.245	1.00	
p	0.398	0.647	0.169	0.876	0.495	0.387	0.042	0.943	0.253	0.419	0	
R^2							0.32					
Time (ms)	0.091	0.066	0.182	0.240	0.052	0.195	0.099	0.025	0.127	0.206	0.052	1.00
p	0.768	0.830	0.552	0.430	0.865	0.523	0.748	0.936	0.680	0.499	0.865	0
R^2												

& (r=0.5-07) Moderate Correlation, * (r=07-0.9) High correlation, # (r>0.9) Very high correlation
R^2: Determination coeficiente; 2D: Second finger length; 4D: Fourth finger length; MIF: Maximum Isometric Strength; RFD: Strength Development Rate

Discussion

The purpose of our study was to evaluate the relationship between the 2D:4D finger length ratio and performance in Paralympic powerlifting. We examined the relationship between the 2D:4D ratio and isometric force indicators, including MIF, RFD, Impulse, Variability, and Time to MIF. However, unlike previous studies, our study found a moderate correlation between RFD and Left D4 ("r" = 0.569) and between Variability and R-L D2:D4 Diff. ("r" = 0.570) and found no correlation between the 2D:4D ratio and any static indicators of force. However, contrary to previous studies, our study did not find a significant correlation between the 2D:4D ratio in the right hand and any strength indicators. We only found a correlation for the left hand, and not for all strength indicators (Baker et al., 2013;

Giffin et al., 2012; Hsu et al., 2015). Although studies have shown that the right hand would present a stronger relationship than the left hand, indicating that the right hand would be more representative of prenatal androgenic influence (Hönekopp & Watson, 2010), our study did not observe this stronger relationship with the right hand, but with the left hand.

We emphasize that the relationship between prenatal androgen exposure and 2D:4D ratio tends to correlate with low 2D:4D and high levels of fetal testosterone to estradiol in amniotic fluid in humans. (Lutchmaya et al., 2004), where human male fetuses tend to have higher levels of androgens in amniotic fluid (van de Beek et al., 2004). Our findings support other studies that suggest that there is no relationship between 2D:4D ratio and levels of sex hormones in adulthood (Hönekopp et al., 2007; Muller et al., 2011). Thus, in our study, there was no relationship between the strength indicators and the 2D:4D ratio, and this seems to have been previously justified. On the other hand, some studies indicate that the proportion of digits would not be related to the serum levels of androgens at rest, but with the levels of androgens as a result of training. (Crewther & Cook, 2019; J. Manning et al., 2014). However, in our study, data was collected at rest and the athletes are continuously subjected to training, being elite Paralympic powerlifting athletes.

On the other hand, the D2:D4 ratio tends to be related to behavioral and morphological traits in adults, due to the fact that 2D:4D is associated with the testosterone and estradiol ratio (Manning, Scutt, Wilson & Lewis-Jones., 1998). In this direction, there are contradictory studies, i.e., with a negative correlation between 2D:4D and testosterone (Coco et al., 2011; Perciavalle et al., 2013), and a positive correlation with Estradiol (McIntyre et al., 2007). On the other hand, as previously mentioned, two reviews did not find an association between the D2:D4 ratio and adult sex hormone levels in normal populations (Hönekopp et al., 2007; J. T. Manning et al., 2004; Muller et al., 2011).

The association of the D2:D4 ratio in relation to performance, negative correlations between 0.4 and 0.6 were observed in modalities such as long distance running, rowing, rugby and surfing, however, weak associations were observed, the same occurring for sports sprint and strength (Hönekopp & Watson, 2010), which is consistent with our findings since Powerlifting is a strength sport. Another point addressed is that higher levels of testosterone would be associated with greater aggression; however, even this relationship proved weak (Butovskaya et al., 2013; Hönekopp & Watson, 2010). On the other hand, it has been suggested that low D2:D4 is associated with high aggressiveness (Millet, 2011), particularly in threatening situations, such as competitions (Millet, 2011; Millet & Dewitte, 2007). In such situations, there would be marked spikes in testosterone levels, and high correlations between 2D:4D and aggressive behavior. In regards to the correlation between the D2:D4 ratio and strength, prenatal testosterone exposure has been shown to provide transient enhancements to strength (Cook & Crewther, 2012; Crewther et al., 2011; Pasanen et al., 2022; Zheng & Cohn, 2011). Prenatal testosterone has been shown to be linked to the expression of several genes involved in its biosynthesis and has been implicated in the regulation of growth and development across a range of physiological systems, including the musculoskeletal system (Pasanen et al., 2022; Zheng & Cohn, 2011). Increased exposure to testosterone during the prenatal period has been demonstrated to enhance force-generating capacity. Furthermore, prenatal testosterone exposure has been shown to stimulate the endocrine system, resulting in transient elevations in circulating testosterone levels (Cook & Crewther, 2012; Crewther et al., 2011). Moreover, a decreased 2D:4D ratio has been found to be associated with increased aggressiveness when challenged, as well as heightened responsiveness to intense training, potentially serving as a potent stimulatory signal (Crewther et al., 2011; Kilduff et al., 2013; Kimura, 1996). In contrast, the D2:D4 ratio has been shown to display a negative correlation with strength, irrespective of covariates such as body size, hormone levels (e.g., testosterone, cortisol), aggression, among others (Kociuba et al., 2019; Ribeiro et al., 2016).

Our study was subject to several limitations. In particular, the analysis of the relationship between 2D:4D and muscle strength was impeded by the significant heterogeneity observed among the studies reviewed (Pasanen et al., 2022). Conversely, there were certain limitations to our study that warrant discussion. For instance, the potential confounding effect of ethnicity, which has been established as a significant factor in previous studies, could not be adequately examined in our study due to the high degree of population heterogeneity. As a result, ethnicity could not be included as a variable in our analyses (Manning et al., 2004, 2007; McGrath et al., 2020). Another limitation of our study pertains to individuals with disabilities. Previous studies have shown that certain pathologies and disabilities can interfere with the 2D:4D ratio (Gámez et al., 2023), as well as psychiatric disorders (Fusar-Poli et al., 2021; Nieuwoudt et al., 2021; Paipa et al., 2018), and other medical conditions (Arazi et al., 2023). Additionally, our study only included male participants, and therefore, it remains unclear how these findings would generalize to female participants.

Conclusion

In the specific case of Paralympic powerlifting athletes, it appears that the D2:D4 ratio did not prove to be a reliable marker, as the finger length ratio showed some weakness in predicting their performance in static strength. On the other hand, there are other indicators of strength, both dynamic and through other tests. In this sense, our study presented weaknesses in relating the D2:D4 ratio to static force indicators.

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Datos de los autores:

Abílio Manoel do Nascimento Rodrigues	Abilio.manoell@gmail.com	Autor/a
Felipe J. Aidar	fjaidar@gmail.com	Autor/a
Márcio Getirana-Mota	marcio_getirana@hotmail.com	Autor/a
Túlio Banja	banja@ufc.br	Autor/a
Georgian Badicu	georgian.badicu@unitbv.ro	Autor/a
Hadi Nobari	hadi.nobari1@gmail.com	Autor/a
Jymmys Lopes dos Santos	jymmys.lopes@gmail.com	Autor/a
Paulo Francisco de Almeida-Neto	paulo220911@hotmail.com	Autor/a
Breno Guilherme de Araújo Tinoco Cabral	brenotcabral@gmail.com	Autor/a
Nuno Domingos Garrido	ngarrido@utad.pt	Autor/a
Taísa Pereira Santos	taisapereira93@hotmail.com	Autor/a
Rapahel Fabrício de Souza	raphaelctba20@hotmail.com	Autor/a
Victor Machado Reis	victormachadoreis@gmail.com	Autor/a
Ciro José Brito	cirojbrito@gmail.com	Autor/a
Lucio Marques Vieira-Souza	profedf.luciomarkes@gmail.com	Autor/a

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Datos de los traductores:

Enago, Crimson Interactive Teléfono: +1-877-712-2177 Traductor