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A COMPARATIVE STUDY OF UPPER EXTREMITY PERFORMANCE, BONE DENSITY AND BODY COMPOSITION IN WHEELCHAIR AND ABLE-BODIED BASKETBALL PLAYERS

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Abstract:
The study aimed to compare upper extremity reactive agility and shooting accuracy between wheelchair basketball players and able-bodied players and to investigate the correlation of these performances with physical parameters, bone density, and body composition. The sample included 18 male basketball players: eight wheelchair players (n=8, 41.7±7.6 years) and ten able-bodied players (n=10, 20.1±1.53 years). Descriptive statistics and independent samples t-tests were used for group comparisons and Pearson's correlation coefficient assessed relationships between quantitative variables. The results indicated no significant difference in shooting accuracy between wheelchair and able-bodied athletes. However, wheelchair athletes showed longer response times and appeared slower in the upper extremity agility test compared to able-bodied athletes, though this difference was not statistically significant. Variations were observed in lean body mass, total bone mineral density (BMD), and lower limb BMD, while upper limb lean mass and bone density did not show significant differences. Handgrip strength was similar between the groups, but there were no notable differences in upper extremity power (medicine ball throw) and specific power (chest pass). Key factors affecting upper agility and shooting accuracy in wheelchair basketball players included the type and degree of disability, upper extremity power, and training background. The results underscore the necessity for customized training to improve shooting accuracy and upper extremity agility in wheelchair athletes, targeting each athlete's individual limitations and building on their strengths.

Keywords: wheelchair basketball, upper extremity agility, shooting accuracy, bone density, body composition, physical performance

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1. Introduction

Typically, the term "agility" refers to lower extremity agility, which describes the ability to change body position quickly, accurately and fluidly while maintaining control and balance in response to a stimulus (Sheppard & Young, 2006; Annesi *et al.*, 2005). In broad terms, agility can be considered a combination of speed, strength, flexibility, coordination, reaction time, and explosiveness. It also involves the level of motor skills required to execute complex and precise movements effectively. Equally important, however, is upper extremity agility, particularly for activities that require fine motor control and dexterity, such as sports or playing a musical instrument, as well as for daily life activities. Upper extremity agility refers to the ability to perform quick and coordinated movements with the arms, hands, shoulders, and elbows. These movements are important for many team sports that require good ball-handling skills, such as basketball. However, compared to the numerous studies examining lower extremity agility (Mackala *et al.*, 2020; Sunita *et al.*, 2018; Šimonek *et al.*, 2017; Darren *et al.*, 2016; Shaun *et al.*, 2013), upper extremity agility, especially in the context of sport for disabled, has not been extensively studied.

Shooting accuracy and scoring percentage in basketball players are strongly linked to their overall performance. An optimal basketball shot results from successful release velocity and angle, incorporating adjustments to current game conditions with motor variability, minimization of release error, and a complex sequence of joint coordination (Slegers, 2021).

1.1 Upper extremity agility in wheelchair basketball

Agility in wheelchair basketball can be described as the ability of athletes to make quick changes in the direction of the wheelchair-athlete system and to handle the ball rapidly. This includes shooting, passing, dribbling, rebounding, and shooting over the head while simultaneously maneuvering the wheelchair during the game. Therefore, upper extremity agility is crucial for the athletic performance of wheelchair basketball players.

1.2 Factors influencing agility

Agility can be categorized into pre-planned agility (changes in direction and speed) and unplanned agility (reactive agility). Generally, agility is influenced by factors such as age, gender, training age, and body mass index (BMI) (Bullock *et al.*, 2012; Baker & Newton, 2008). However, many studies suggest that agility depends on a combination of physical and cognitive factors. A research by Scanlan *et al.* (2014) observed that cognitive indicators had a greater impact on reactive agility performance in male basketball players compared to physical indicators. Conversely, a study by Pehar *et al.* (2017) that investigated the relationship between the two forms of agility and anthropometric and motor indicators in high-performance male basketball players found that pre-planned agility is directly associated with the reactive strength (broad jump) while reactive agility is associated with anthropometric indicators (height, weight, body fat percentage).

Body composition also plays a significant role in agility performance. A recent study involving wheelchair athletes showed a significant difference in total fat and total mass between genders, while no significant difference was found between paraplegic and quadriplegic athletes. Notably, there was considerable variation across different sports, with basketball players exhibiting the highest percentage of muscle mass (Flueck, 2020). Athletes with lower body fat percentages demonstrated better results and required less time in agility tests. Additionally, lean mass, particularly skeletal muscle tissue in the upper body, significantly impacts the performance of wheelchair athletes.

Special attention should be given to the factor of "type and degree of disability," which is crucial for the agility of wheelchair players. There is a limited amount of research on upper extremity agility in wheelchair athletes relative to their disabilities, despite the importance of hand agility in many sports. One of the few studies (Nunome *et al.*, 2002) found that individuals with tetraplegia maximize the use of their available muscular system to compensate for the wrist flexor muscles dysfunction. For instance, athletes with tetraplegia exhibited reduced ball release speed due to insufficient angular velocity in wrist flexion. It was observed that a specific horizontal shoulder adduction movement required a greater range of shoulder abduction and larger displacements of the right shoulder. These movements helped to maximize the function of the available muscles around the elbow and shoulder joints, compensating the wrist flexor dysfunction and contributing to the ball release speed. This suggests that each athlete may compensate for their motor weaknesses in different ways to achieve performance goals, adapted to their individual motor profile. Further research on the influence of biomechanical limitations due to disability on upper extremity agility is necessary.

1.3 Shooting accuracy from a seated position

The seated position impacts the shooting accuracy of wheelchair basketball players, influencing the biomechanical characteristics of the shot. The kinematics of free throws differ between wheelchair basketball players and able-bodied players, particularly in terms of the release angle of the ball. This suggests that each athlete may compensate for their motor weaknesses in different ways to achieve performance goals, adapting to their individual motor profile. Wheelchair players tend to have a higher release angle compared to able-bodied players, who exhibit better upper limb motor skills and perform the shot standing, with the assistance of their lower limbs (Özdalyan *et al.*, 2022). A key factor in the biomechanical behavior of wheelchair players is their positioning during the shot, including whether they shoot from the center, the right or left side, or -more crucially- whether the shot is executed with the wheelchair stationary or in motion. All these factors affect the force, release height, and shooting angle (Francis, 2019; Francis *et al.*, 2016).

1.4 Factors influencing shooting accuracy

Many studies suggest that shooting accuracy in basketball is primarily a result of good concentration rather than upper extremity strength or agility, and that stress significantly affects shooting accuracy (Besse *et al.*, 2023; Lu & Li, 2022; Candra O. & Foster N., 2020; Metulini & Le Carre, 2019; Bali, 2015). Players' personality and their ability to manage emotions during a game are also important. Campbell & Jones (2002) found personality differences between wheelchair basketball players and professional basketball players, with the former being more emotional and impulsive, showing less emotional stability and a tendency towards anxiety.

Shooting accuracy in basketball also depends on physiological factors, as the shooting technique requires various execution speeds and the application of appropriate force levels. Additionally, accuracy is dependent on eye-hand coordination to execute the precise sequence of movements required for the shot. This coordination, in synergy with concentration, is highly related to shooting accuracy in basketball (Besse *et al.*, 2023).

The degree of disability in wheelchair basketball players can impact their shooting accuracy as well, due to altered biomechanics, limited mobility, and the need for adaptations in technique and posture. A study by Zacharakis (2020) concluded that athletes with severe disabilities had the lowest scores in technical skill tests, which were largely attributable to the characteristic motor impairments, rather than anthropometric factors. Studies (Prvulovic *et al.*, 2022; Tachibana *et al.*, 2019; Cavedon, Zancanaro & Milanese, 2015; Malone *et al.*, 2002; Laurie *et al.*, 2002) examining the relationship between shooting mechanics and the classification of wheelchair basketball players observed that shooting accuracy primarily depends on the degree of their disability, as they exhibit different mechanisms for achieving successful shots.

A negative correlation was found between free throw accuracy and the variability of hip angular velocity at the moment of ball release, indicating that wheelchair basketball players with greater hip stability demonstrate quicker response to stimuli and higher accuracy in executing movements compared to players with lower hip stability (Shigematsu *et al.*, 2021). In relation to that, an important factor affecting the accuracy of free throws in wheelchair basketball has been shown to be the players' position in their wheelchairs. Players sitting lower in wheelchairs (due to hip instability) exhibited higher release speeds and greater accuracy, influenced primarily by body type (long or short torso) (Ogawa *et al.*, 2019; Goosey-Tolfrey *et al.*, 2002).

Body composition may also be a significant factor, especially in wheelchair sports, where players with spinal cord injuries might experience a loss in metabolic activity in muscle mass (Collins *et al.*, 2010). Studies on body composition in wheelchair basketball and tennis (Sutton *et al.*, 2009) indicate that both the functional capacity of players and their body composition affect physical performance in wheelchair basketball (Vanlandewijk *et al.*, 2004; Goosey-Tolfrey *et al.*, 2003). Considering that wheelchair basketball is an intermittent sport involving repeated high-intensity sprints (Molik *et al.*, 2010), physical performance levels are fundamental for shooting success, as prolonged fatigue during offensive and defensive situations can significantly impact shooting accuracy (Cengizel *et al.*, 2023; Ardigò *et al.*, 2018).

1.5 Importance of the study

The importance of this research lies in highlighting the significant differences in agility and shooting accuracy among wheelchair basket players and recommending practical agility assessment tools, which can map the motor profile of each wheelchair athlete, determined by the type and degree of their disability. These data are important in the training process as they identify specific areas of weakness and the level of improvement required for each athlete, enabling the design of targeted training programs aimed at enhancing their shooting accuracy and upper extremity agility. Additionally, comparing their performance with that of able-bodied basketball players can guide coaches on whether and when training methods used for able-bodied athletes can be effectively applied or if modifications are needed to meet the specific needs of wheelchair athletes.

2. Material and Methods

2.1 Sample

The study involved eighteen (n=18) volunteer male basketball players: eight (n=8) officially classified wheelchair athletes playing in the Greek A1 wheelchair basketball League and ten (n=10) able-bodied athletes from the Basketball Team of Democritus University of Thrace. Criteria for participant selection included active engagement in their team's training sessions during the current year, competitive participation, and the absence of recent injuries. The athletes' individual characteristics, including training experience and anthropometric data, were recorded prior to the measurement procedure (Table 1). Additionally, information was provided about the type and grade of disability among wheelchair basketball players and its associated movement limitations (Table 2).

Table 1: Age, training experience and anthropometric characteristics of the participants

	Wheelchair Athletes	Able-bodied Athletes
Age (years)	41,68±7,6	20,1±1,53
Training Age/Experience (years)	6,5±4,2	4±1,94
Height (m)	1,76±0,10	1,87±0,07
Body Mass (kg)	81,2±18,1	85,2±9,9
BMI (kg/m²)	26,1+5,1	24,8±2,16
Body Fat Percentage (% fat)	31,45±13,8	19,49±5,5
Lean Mass (g)	52,55±4,1	62,95±5,32
Total Bone Density (g/m²)	1,238±0,06	1,327±0,09
Upper Extremity Bone Density (g/m²)	1,028±0,11	1,007±0,095

Table 2: Types and duration of disabilities among the wheelchair basketball players

Type of Disability	Duration of Disability
Amputation of right lower limb	36 yrs
Spastic tetraparesis	congenital
Quadriplegia (spinal cord injury)	10 yrs
Amputation of right lower limb	18 yrs
Rheumatoid arthritis	congenital
Spastic paraparesis	congenital
Inflammatory polyneuropathy	5 yrs
Paraplegia (spinal cord injury)	congenital

2.2 Experimental procedure

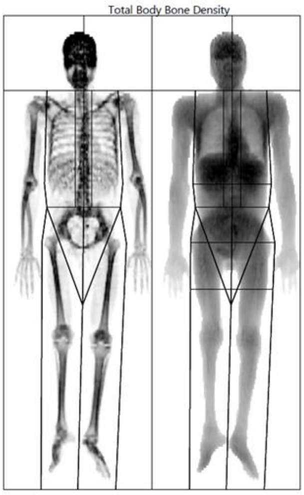
The experimental procedure was conducted over two (2) subsequent sessions:

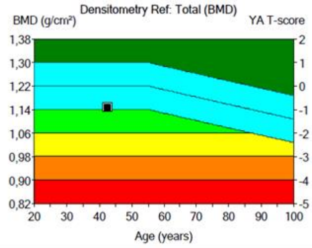
- **First session**: Participants were informed about the purpose of the study, the experimental design and measurements, and were asked to complete and sign a consent form. Data on age, training experience and disability type were collected, followed by the assessment of body composition and bone density, which lasted approximately 15-20 minutes per participant.
- **Second session:** Assessments evaluated upper extremity agility (Fitlight-test), shooting accuracy, chest pass performance, upper extremity power, and handgrip strength. Participants were instructed to avoid any form of training or intense physical activity 1-2 days prior to the assessment to ensure optimal performance. A 5-minute warm-up was conducted prior to the tests, involving "running" in the wheelchair, followed by dynamic stretches with an emphasis on the muscle groups that would be activated during the tests.

All the measurements were carried out at the Physical Performance Laboratory, the Motor Performance Laboratory, and the basketball court at the School of Physical Education and Sport Science (S.P.E.S.S.) at Democritus University of Thrace (D.U.Th.).

2.3 Bone density and body composition measurements

Bone density (Figure 1) and body composition were assessed using Dual Energy X-ray Absorptiometry (DEXA; Lunar DPX-NT, GE Healthcare, Diegem, Belgium). Participants were required to fast overnight and wear light clothing without any metallic objects.





Densitometry (Basic Analysis)

Region	BMD[1] (g/cm²)	Young-Adult[2] (%)	Young-Adult T-score	Age-Matched[3] (%)	Age-Matched Z-score
Total	1,148	94	-0,9	94	-0,9

ANCILLARY RESULTS: Total Body (Basic Analysis)

Region	BMD[1] (g/cm²)	Young-Adult[2] (%)	Young-Adult T-score	Age-Matched[3] (%)	Age-Matched Z-score	BMC (g)	Area (cm²)
Head	2,280	-	-	-	-	595	261
Arms	0,952	-	-	-	-	578	607
Arm Right	0,955	-	-	-	-	293	307
Arm Left	0,949	-	-	-	-	285	300
Legs	1,154	-	-	-	-	852	738
Leg Right	1,123	-	-	-	-	395	351
Leg Left	1,182	-	-	-	-	457	387
Trunk	0,939	-	-	-	-	811	863
Trunk Right	0,913	-	-	-	-	397	435
Trunk Left	0,965	-	-	-	-	413	429
Ribs	0,753	-	-	-	-	325	431
Spine	1,100	-	-	-	-	276	250
Pelvis	1,158	-	-	-	-	210	182
Total	1,148	94	-0,9	94	-0,9	2.835	2.470
Total Right	1,160	-	-	-	-	1.459	1.258
Total Left	1,135	-	-	-	-	1.376	1.212

Figure 1: Assessment of Total and Regional Bone Density

2.4 Test Protocols for upper extremity agility and shooting accuracy

- **Upper extremity agility test** (Fitlight System)

Agility and reaction time of the upper extremities were assessed using the FITLIGHT Trainer™, a wireless reflex measurement system with illuminated units controlled by a mobile device or tablet. The LED units activated randomly and sequentially, prompting participants to respond immediately and swiftly. The units automatically deactivated when the participant passed in front of them or touched them, with the impact sensor recording the time elapsed from activation to deactivation.

Procedure: All athletes performed the test in a wheelchair positioned in front of a wooden platform (80cm height, 50cm width**)**, allowing the participants to reach the illuminated units attached to the platform and the wall (Figure 2). Seven (7) units were used: four (4) were affixed on the flat surface, and three (3) were mounted on the wall, arranged at distances accommodating all participants regardless of body size or disability. Each participant completed two (2) attempts, aiming to hit all twenty units in the shortest possible time. Performance data were automatically recorded on the tablet via the FITLIGHT App. Able-bodied athletes were instructed not to lift of their thighs off the wheelchair seat.

Figure 2: Assessment of upper extremity agility using the FITLIGHT Trainer™

- **Shooting accuracy test** (free throw)

To evaluate shooting accuracy, all participants executed ten (10) free throw attempts from a wheelchair (Ferreira da Silva *et al.*, 2022) positioned at the free throw line. The number of successful shots out of the ten attempts was recorded.

2.5. Measurements of physical performance parameters

- **Handgrip strength**

Handgrip strength was evaluated using a digital hand dynamometer (Charder MG480-Wireless Digital Grip Dynamometer) from a seated position (Figure 3). Each participant performed two maximal attempts with a one-minute rest, and the best performance was recorded. The seated position with the elbow flexed was chosen for practical reasons to ensure consistent testing conditions for both ambulatory and wheelchair-bound athletes, due to the limited mobility of wheelchair athletes, who would otherwise be unable to perform the test correctly with the wheelchair wheel interfering between the body and the extended evaluation arm.

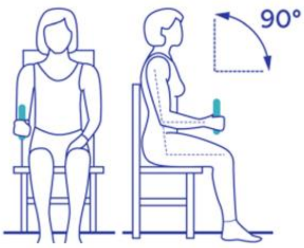


Figure 3: Grip strength evaluation in a seated position (Mutalib *et al.*, 2022)

- **Upper extremity-specific power** (Seated Chest Pass with Basketball)

All participants performed three (3) attempts of a chest pass with a basketball from a seated position in the wheelchair (Petrigna *et al.*, 2022; Marszałek *et al.*, 2019). Able-bodied participants were instructed to keep their pelvis stationary on the wheelchair seat. The starting position is all set at the chest, with the hands and ball close to the sternum (Figure 4). Measurements were taken using a measuring tape from the vertical point of the footrest to the point where the ball landed. The best performance was recorded.

Figure 4: Evaluation of upper extremity-specific muscular power with the chest pass test

- **Upper extremity power** (seated overhead medicine ball throw)

Participants, seated in wheelchairs, performed (3) overhead throws with a 5kg medicine ball (Ribeiro *et al.*, 2022; Gomes Costa *et al.*, 2021). Able-bodied individuals were again instructed not to lift their pelvis from the wheelchair seat. To stabilize the wheelchair, an assistant was positioned behind each participant, providing resistance to counteract the forceful dynamic movement of the athletes, which could disrupt balance and pose a risk of falling (Figure 5). Measurements were taken as in the previous evaluation.

Figure 5: Evaluation of upper extremity power with the medicine ball throw test

2.6 Statistical analysis

Descriptive statistics included the mean (M) and standard deviation (SD). Independent samples t-tests were used for group comparisons, assuming equal variances. In case of not homogeneous variances, the non-parametric Mann-Whitney U test was applied. Pearson's correlation coefficient assessed relationships between quantitative variables. The significance level was set at α=0.05 for all statistical tests. Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL, USA) software, version 25.

3. Results

The dependent variables in this study were defined as the main tests of the experimental design: (1) shooting accuracy from a wheelchair, (2) the total time to complete 20 hits on the Fitlight system, and (3) the average time per hit. Total lean body mass, fat mass, and total body bone density, as well as bone density and composition of the upper and lower extremities, were evaluated and correlated with these performances. Finally, the study examined whether there is a correlation between performance factors such as grip strength (grip test), upper extremity power (medicine ball throw), and specific power (chest pass) with upper extremity agility and accuracy.

3.1 Upper extremities agility and shooting accuracy

Descriptive statistics for shooting accuracy in 10 free throw attempts, the total time to complete 20 hits on the Fitlight system, and the average time per hit are presented in Table 3 for both able-bodied and wheelchair basketball athletes.

Table 3: Comparison of mean performance scores in experimental design tests

		free throw accuracy	average hit time	total time (20 hits)
wheelchair players	Mean	3.13	.539	16.02
	Std. Deviation	2.42	.153	3.093
able-bodied players	Mean	2.80	.446	14.11
	Std. Deviation	2.01	,038	,6784

Wheelchair basketball players did not show a significant difference in shooting accuracy (M = 3.13, SD = 2.42) compared to able-bodied players (M = 2.80, SD = 2.01), as indicated by the Mann-Whitney non-parametric test (p = .897 > .05).

In Table 3, a difference is observed in the total execution time and the average time per hit in the Fitlight test, where able-bodied athletes completed the test faster (M = 14.11, SD = 0.6784) and (M = 0.539, SD = 0.153) compared to wheelchair athletes (M = 16.02, SD = 3.093) and (M = 0.801, SD = 0.153). However, this difference was not statistically significant (p = .408 and p = .315 > .05). As shown in Figure 6, wheelchair basketball players exhibited greater variability in their performance compared to able-bodied athletes, indicating a higher degree of internal score variation.

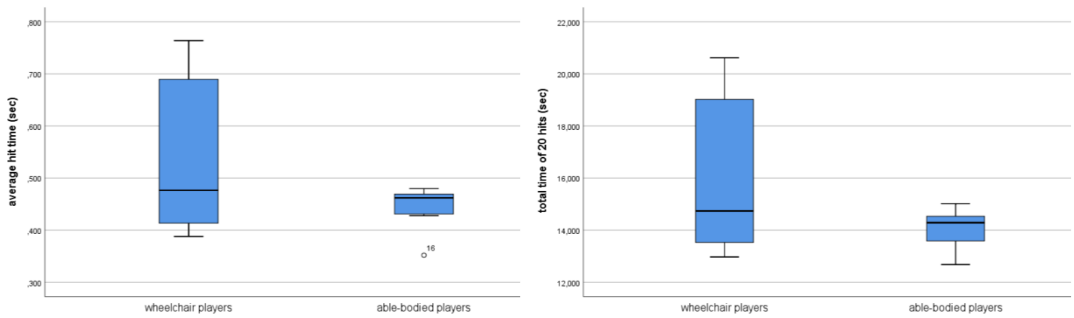


Figure 6: Performance scores for both groups in the FITLIGHT test

To determine the existence of a correlation between performance in the experimental tests and factors such as physical performance, body composition, and training age, the Pearson r correlation coefficient was calculated. The results indicated a statistically significant correlation at the $\alpha = 0.05$ level between the total execution time of the 20 hits in the Fitlight test and grip strength, as well as power. A similar correlation was found between the average time per hit (reaction) and the same parameters. Additionally, the training age parameter, reflecting experience in performing throws, showed a high correlation with shooting accuracy (r = .663, p = .003 at the .01 significance level). The overall values of the Pearson correlation coefficient are presented in Table 4.

Table 4: Correlation of tests performance with physical performance parameters and training age

Correlations

		grip test R	grip test L	upper extremity power	chest pass	training age
shooting accuracy	Pearson Correlation	,344	,347	,144	,203	,663**
	Sig. (2-tailed)	,162	,159	,568	,419	,003
total time (20 hits)	Pearson Correlation	-,471*	-,560*	-,479*	-,574*	-,243
	Sig. (2-tailed)	,049	,016	,045	,013	,331
average hit time	Pearson Correlation	-,487*	-,581*	-,483*	-,577*	-,213
	Sig. (2-tailed)	,040	,011	,042	,012	,397

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

3.2 Body composition and bone density

The level of lean body mass, total bone mineral density (BMD), and lower extremity BMD showed statistically significant differences between able-bodied athletes and athletes with disabilities according to the non-parametric Mann-Whitney test (p = .001, .034, .000, respectively). In contrast, the lean mass of the upper extremities and upper extremity BMD did not show significant differences (Figure 7).

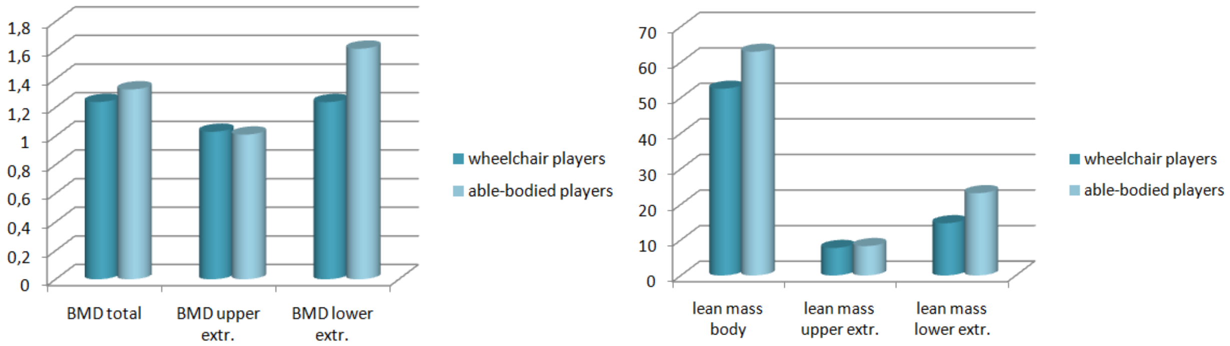


Figure 7: Comparison of mean bone density and body composition of the sample

Pearson's correlation coefficient indicated that upper extremity power (medicine ball throw) and specific power (chest pass) were negatively correlated with the total body fat of athletes (r = - .507, p = .022 and r = - .582, p = .011 respectively, at the .05, significance level). Conversely, these measures of power were positively correlated with lean body mass (r = .591, p = .010 and r = .586, p = .011). Similarly, upper extremity BMD showed a high correlation with handgrip strength (r = .518, p = .028 at the .05 significance level) (Table 5).

Table 5: Correlation of body composition and
bone density with physical performance parameters

Correlations

		grip test R	grip test L	upper extremity power	chest pass
BMI	Pearson Correlation	-,305	-,268	-,260	-,316
	Sig. (2-tailed)	,218	,282	,298	,202
fat %	Pearson Correlation	**-,385**	-,330	**-,507***	**-,582***
	Sig. (2-tailed)	**,115**	,182	**,032**	**,011**
lean mass	Pearson Correlation	,226	,225	**,591****	**,586***
	Sig. (2-tailed)	,368	,369	**,010**	**,011**
BMD total	Pearson Correlation	,267	,240	,383	,473*
	Sig. (2-tailed)	,284	,338	,117	,048
BMD upper extremity	Pearson Correlation	**,518***	,450	,317	,184
	Sig. (2-tailed)	**,028**	,061	,200	,464

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Overall, handgrip strength in both the right and left hands did not show significant differences. However, statistically significant differences were observed between able-bodied basketball players and wheelchair basketball players in upper extremity power (measured by performance in the medicine ball throw) and specific power (measured by the chest pass). Descriptive statistics of the physical performance parameters for able-bodied athletes and wheelchair basketball players are presented in Table 6.

Table 6: Comparison of mean performance scores in physical performance tests

		grip test (kg) R	grip test (kg) L	upper extremity power (m)	chest pass (m)
wheelchair players	Mean	39,900	39,400	3,6375	8,5750
	Std. Deviation	19,3478	18,5141	1,02530	3,09366
able-bodied players	Mean	48,920	48,240	5,0200	14,2600
	Std. Deviation	6,2329	4,2539	,49171	,98680

4. Discussion

The aim of this study was to investigate whether wheelchair basketball players display different performances in upper extremity agility and shooting accuracy compared to able-bodied players and if these performances are influenced by factors of physical performance and body composition. Wheelchair basketball involves complex movement patterns that require efficient use of the upper extremities for actions such as shooting, passing, dribbling, and rebounding. The findings of this study underscore that the technical and physiological demands in wheelchair basketball may be greater compared to able-bodied basketball due to the additional challenge of maneuvering the wheelchair while performing these tasks.

4.1 Shooting accuracy

Various researches support the study's observation of similar shooting accuracy between able-bodied and wheelchair basketball players, highlighting that shooting from a seated position involves different biomechanical adjustments compared to shooting from a standing position. Able-bodied players generally benefit from leg propulsion and optimal body positioning, which contribute to higher shooting accuracy (de Oliveira *et al.*, 2009). Despite these biomechanical differences, high-level athletes from both groups demonstrate an impressive ability to adapt alterations to their techniques effectively. This adaptability is evidenced by the strong correlation between shooting accuracy and "training age," reflecting the level of training experience (Mikić *et al.*, 2024; Alsasua *et al.*, 2021). Such findings align with research on shooting biomechanics and wheelchair positioning, emphasizing the importance of adequate technique and body position in achieving accuracy (Francis, 2019; Özdalyan *et al.*, 2022).

4.2 Agility performance of upper extremities

The performance of upper extremity agility, measured with the Fitlight test involving multiple explosive hits, showed significant correlations with upper limb power and reaction times. This finding aligns with research demonstrating that agility tests involving rapid responses are strongly related to upper body strength and power (Badau *et al.*, 2023; Silvestri *et al.*, 2023). The effectiveness of Fitlight system in assessing and training agility, as well as its application in enhancing motor abilities, supports its value as a tool for both measurement and training in athletes with disabilities (Tatlıici & Özer, 2023). The correlation between the Fitlight test results and handgrip strength corroborates the role of physical performance in agility, as similar results were found in studies focusing on neuromuscular performance and reaction times (Petrigna *et al.*, 2022; Ferreira *et al.*, 2022).

4.3 Grip strength and power

Handgrip strength was found to be significantly correlated with reaction time and performance in the Fitlight agility tests. This supports previous studies indicating that handgrip strength is a crucial component of upper extremity performance in wheelchair basketball, impacting reaction speed, overall agility and handling effective the ball (Gil *et al.*, 2015; Yanci *et al.*, 2015). Additionally, upper extremity power, measured through tests like the medicine ball throw, was closely related to lean body mass and shooting accuracy, reinforcing the importance of muscle strength in athletic performance (Iturricastillo *et al.*, 2022; Ferreira *et al.*, 2022; Petrigna *et al.*, 2022). This relationship is supported by studies linking muscle strength with rapid performance outcomes in various sports (Bullock *et al.*, 2012; Baker & Newton, 2008).

4.4 Body composition and bone mineral density (BMD)

The study identified significant differences in body composition between able-bodied athletes and wheelchair basketball players, specifically in terms of total lean body mass, upper extremity lean mass, and BMD. These findings are consistent with research, indicating that wheelchair athletes often have higher body fat percentages due to reduced overall activity (Flueck, 2020). However, the lean mass of the upper limbs and upper extremity BMD did not differ significantly between the two groups. This is supported by studies showing that wheelchair athletes tend to maintain or even enhance upper body muscle mass and bone density due to the increased mechanical load placed on these areas (Sutton *et al.*, 2009; Collins *et al.*, 2010).

The high correlation observed between upper extremity BMD and handgrip strength further emphasizes the role of bone density in supporting muscular strength and performance (Yildirim *et al.*, 2010). This relationship highlights the importance of maintaining bone health in athletes who rely heavily on their upper body strength. Body composition, particularly lean mass and fat percentage, has been shown to impact physical performance, with lower fat percentages generally correlating with better agility and performance (Flueck, 2020; Vanlandewijk *et al.*, 2004).

4.5 Training age

Finally, the correlation between training age and performance underscores the importance of experience in executing shots and improving agility (Kamble, Daulatabad & Baji, 2012). Training age reflects the duration and intensity of practice, which is crucial for refining skills and adapting techniques to specific conditions, whether seated or standing (Mikić *et al.*, 2024; Alsasua *et al.*, 2021). This finding supports the notion that targeted and sustained training can lead to significant improvements in athletic performance, particularly in sports involving specialized skills and adaptations (Cengizel *et al.*, 2023; Ardigò *et al.*, 2018). That can be achieved through specific exercises and regular practice, focusing on hand-eye coordination, fine motor control, speed, accuracy, and reaction time (Mackala *et al.*, 2020; Scanlan *et al.*, 2013;).

5. Conclusion and Recommendations

The results of the present study highlighted key factors influencing upper limb agility and shooting accuracy in wheelchair basketball players, including disability type and degree, upper limb power and training experience. It was observed, that variations in performance often reflect differences in mobility, muscle function and body composition associated with each disability.

These findings provide valuable insights into the performance characteristics of wheelchair basketball players and suggest that tailored training programs addressing individual needs and disability-specific factors can further enhance performance. Future research should continue to explore these aspects and compare more homogeneous groups of wheelchair athletes with similar disability types and degrees, training levels, and experience to refine training methodologies further.

Moreover, wireless systems designed to measure and train response speed and reflexes have proven their effectiveness in enhancing sensory-cognitive and motor abilities. The system used in this study proved to be a valuable performance measurement tool, providing accurate data that can guide training improvements. Further research should evaluate the reliability and effectiveness of such tools in diverse training contexts.

Conflict of interest statement
The authors declare no conflicts of interest.

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