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ORIGINAL RESEARCH

Relationship between functional classification, upper extremity muscle strength, and agility in wheelchair rugby athletes

A relação entre classificação funcional, força muscular de membros superiores e agilidade de atletas do rúgbi em cadeira de rodas

La relación entre la clasificación funcional, la fuerza muscular de las extremidades superiores y la agilidad de los deportistas de rugby en silla de ruedas

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ABSTRACT | This study aimed to compare the strength and agility of wheelchair rugby (WR) athletes with different functional classifications (FC) and describe the relationship between agility and upper extremity isometric muscle strength (IMS). A total of 10 WR athletes were analyzed, divided into two groups: Group 1 (G1): FC 0.5 and 1.0; and Group 2(G2): FC 1.5 to 2.5. IMS was evaluated by a dynamometer, and agility by a zig-zag test. Spearman's correlation was used to describe the relationship between IMS and performance on the agility test. In contrast, the t-test was used to compare strength and agility between different FCs ($p \leq 0.05$). Shoulder extensor IMS was higher in G2 athletes (p=0.001; d=3.10), which were also more agile than G1 athletes (G1=23.66s>G2=17.55s; p=0.015; d=2.00). Both groups showed a correlation between bilateral shoulder extensor strength and agility (r=−0.721; p=0.019). Athletes with high FC scores are more agile than athletes with low scores and, therefore, have greater movement speed when performing WR tasks. Greater shoulder extensor muscle strength is associated with greater agility in WR athletes.
Keywords | Para-Athletes; Wheelchairs; Muscle Strength.

RESUMO | O objetivo do estudo foi comparar a força e a agilidade de atletas do rúgbi em cadeira de rodas (RCR) por meio de diferentes classificações funcionais (CFs), bem como descrever a relação da agilidade com a força muscular isométrica (FMI) de membros superiores. Foram analisados 10 atletas de RCR, divididos em dois grupos: Grupo 1 (G1): CF 0,5 e 1,0; e Grupo 2 (G2): CF 1,5 a 2,5. A FMI foi avaliada pela dinamometria, e a agilidade pelo teste em ziguezague. A correlação de Spearman foi utilizada para descrever a relação entre a FMI e o desempenho no teste de agilidade, enquanto o teste t foi usado para comparar a força e a agilidade entre as diferentes CFs ($p \leq 0,05$). A FMI dos extensores do ombro foi maior no G2 (p=0,001; d=3,10), que também se mostrou mais ágil que o G1 (G1=23,66s>G2=17,55s; p=0,015; d=2,00). Verificou-se a correlação entre força muscular bilateral de extensores de ombro e agilidade em ambos os grupos (r=−0,721; p=0,019). Atletas com pontuação alta na CF são mais ágeis comparados a atletas com pontuações baixas e, portanto, apresentam

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maior velocidade de deslocamento ao executar as tarefas do RCR. Maior força muscular dos extensores de ombro é associada à maior agilidade em atletas do RCR.
Descritores | Paratletas; Cadeiras de Rodas; Força Muscular.

RESUMEN | El objetivo de este estudio fue comparar la fuerza y la agilidad de los deportistas de rugby en silla de ruedas (RSR) desde diferentes clasificaciones funcionales (CF), así como describir la relación entre la agilidad y la fuerza muscular isométrica (FMI) de las extremidades superiores. Se evaluaron a diez deportistas RSR en dos grupos: Grupo 1 (G1): CF 0,5 y 1,0; y Grupo 2 (G2): CF 1,5 a 2,5. En la evaluación de la FMI se utilizó la dinamometría; y en la evaluación de la agilidad, la prueba de zigzag. La correlación de Spearman se utilizó para describir la relación entre la FMI y el rendimiento en la prueba de agilidad, mientras que la prueba t se utilizó para comparar la fuerza y la agilidad entre las diferentes CF (p≤0,05). La FMI de los extensores del hombro fue mayor en el G2 (p=0,001; d=3,10), y este también fue más ágil que el G1 (G1=23,66s>G2=17,55s; p=0,015; d=2,00). Hubo una correlación entre la fuerza muscular bilateral de los extensores del hombro y la agilidad en ambos grupos (r=−0,721; p=0,019). Los deportistas con altas puntuaciones de CF fueron los más ágiles en comparación con aquellos con bajas puntuaciones, por lo tanto, se constata que tienen una mayor velocidad de desplazamiento en la realización de tareas de RSR. Una mayor fuerza muscular de los extensores de hombro se asocia con una mayor agilidad en los deportistas RSR.
Palabras clave | Paratletas; Silla de Ruedas; Fuerza Muscular.

INTRODUCTION

Currently, wheelchair sports have become more popular, making sports practice among people with disabilities more sought after by both new fans and spectators. In this context, the search for high performance in sports highlights the need to understand the factors influencing athletes' performance[1-3].

Among the sports adapted for people with physical disabilities who use wheelchairs, wheelchair rugby (WR) is a paralympic team sport developed for athletes with spinal cord injuries (quadriplegic individuals), cerebral palsy, multiple amputations, and neuromuscular diseases. For a fairer competition, athletes are allocated to functional classes (FCs), which consider both their individual physical features and the specific characteristics of the sport. The score resulting from the functional classification ranges from 0.5 (major impairments) to 3.5 (minor impairments)[4].

Studies suggest that athletes with higher scores perform better on WR. This relationship between FC and performance is probably due to greater shoulder stability and capacity for trunk, wrist, and hand movements[5,6], which are skills that directly interfere with wheelchair propulsion technique, balance, and rhythm, and consequently affect sports performance[7]. During propulsion movement, upper extremity muscles, especially the shoulder complex, undergo joint activation. The shoulder flexors are primary muscles during the push phase; the shoulder extensors are dominant in the recovery phase, with increased co-contraction of the shoulder muscles during the transition between propulsion and deceleration of the wheelchair[8].

The main purposes of propulsion in WR are acceleration, sprinting, braking, spinning, and blocking, and in all these sportive gestures, strength and neuromuscular control are essential. To assess upper extremity muscle strength, such as shoulder and elbow strength, manual dynamometry can be used[9,10], since it is a low cost and easy-to-apply method, with reliability and validity tested among wheelchair athletes[11,12]. Moreover, it has high efficacy, competing with isokinetic dynamometry[13].

Researchers have investigated the mechanical loads imposed on the upper extremities of wheelchair users[14] and their many variations according to the task, the environment, the individual, and the presence or absence of injury[15], muscle fatigue[16], or pain[17]. However, the studies apply tests in a laboratory environment with equipment that is not accessible to technical teams in practice. Therefore, this study aimed to compare the agility of WR athletes with different FC scores and describe the relationship between agility and isometric muscle strength (IMS) of shoulder flexors, extensors, and abductors and elbow flexors and extensors.

METHODOLOGY

Ethical aspects

All participants signed the informed consent form and were duly informed about the risks and benefits of the study.

Selection criteria

Athletes who had already undergone a functional classification process conducted by official evaluators and who compete at the national and/or international level were included in this study.

Athletes undergoing medical treatment for upper extremity musculoskeletal dysfunctions and individuals who have suffered an upper extremity injury that forced them to interrupt their training routine in the previous six weeks were excluded from the sample. This study also excluded athletes who, on the day of the tests, had at least one of the following clinical signs in the physical examination conducted by the team physiotherapist: pain of any intensity during active abduction, flexion, and resisted extension of the shoulder; pain of any intensity during active flexion and resisted extension of the elbow; or phlogistic signs in the upper extremities (redness, warmth, swelling, dysfunction).

Sample definition

The sampling was by convenience and 10 quadriplegic athletes with spinal cord injury, members of a WR team, participated. Four had cervical injury level 5 (C5); three C6; two C7; and one C8. The mean time of spinal cord injury was 10.9±4.5 years; the age range of participants was 33.8±6.3 years; and the time practicing the sport was 7.4±2.2 years. Regarding FC, four athletes scored 0.5; one 1.0; one 1.5; two 2.0; and two 2.5.

Study design

Initially, a sociodemographic questionnaire was applied to collect descriptive information from the sample, and then the athletes put on the training equipment and used the wheelchair specific for WR practice. They were instructed by the team coach to perform a usual warm-up, with three minutes of upper extremity educational exercises and seven minutes touching the wheelchair at a moderate speed. After the warm-up, the athletes had two minutes for hydration, and then the isometric strength tests were conducted, as described in the following section. All participants performed the test applied by the same evaluator and rested for five minutes before the agility test.

Isometric muscle strength (IMS) test

For IMS assessment, a microFET2 handheld dynamometer (HHD, Hoggan Health Industries, Draper, UT, USA) was used to analyze the peak values of isometric strength.

The IMS test consisted of performing three maximum isometric contractions of the shoulder flexors, extensors, and abductors and the elbow flexors and extensors for three seconds, with 10-second rest intervals in between[12]. The standardized rest between muscle groups was one minute[12], and data analysis considered the mean of the three trials. Bilateral strength values were obtained by adding the results of both upper extremities divided by two.

Regarding the positioning of the athlete in the wheelchair, the stabilizing straps were checked, and the training wheelchair was locked. Participants were instructed to exert isometric force against the evaluator's hand to confirm their understanding of the test. The evaluator guided athletes regarding the positioning of the tested upper extremity, the contralateral arm, and the trunk in order to avoid compensatory strategies.

To test the shoulder abductor, the arm was aligned with the trunk and slightly abducted, simulating the contact of the hand with the wheelchair rim; the elbow remained in full extension, and the dynamometer was in contact with the posterior distal surface of the wrist, which was in neutral position (Figure 1A). For shoulder flexor, the arm remained in the same position while the circular surface of the dynamometer was placed in contact with the posterior distal surface of the forearm, close to the wrist in neutral position (Figure 1B). For shoulder extensor, the arm remained in the same position; the elbow was slight flexed, and the dynamometer remained in contact with the distal posterior surface of the humerus (Figure 1C).

For elbow flexion and extension, the arm remained flexed at 90°; the shoulder was aligned with the trunk, and the dynamometer was placed in contact with the wrist. Five athletes with low FC scores (G1=0.5 and 1.0) had no elbow extensor function (Figures 1D and 1E).

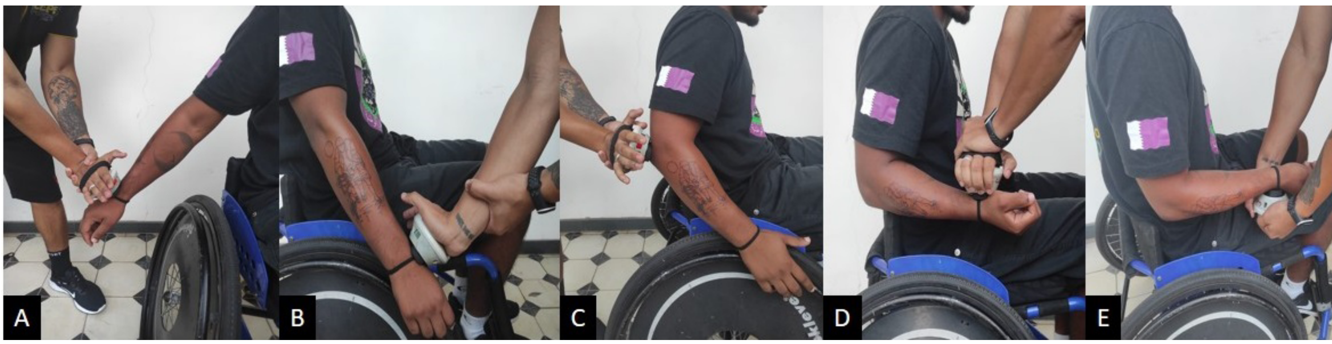


Figure 1. Manual isometric muscle strength tests: (A) Shoulder abductor strength; (B) Shoulder flexor strength; (C) Shoulder extensor strength; (D) Elbow flexor strength; (E) Elbow extensor strength

Zig-zag agility test (AT)

Once the strength measurements were completed, the athletes rested for five minutes and then performed the AT according to the protocol pre-established by Gorgatti and Böhme[18] with only one change: in this study, the rest time between trials was 40 seconds.

The route points were marked vertically with cones and horizontally with lines and arrows showing the starting point of the circuit and changes in direction[13]. One evaluator was at the finishing point of the circuit and another at an intermediate point, both equipped with a stopwatch accurate to one tenth of a second.

At the signal from the evaluator with the stopwatch, the athlete pushed the wheelchair along the circuit at the highest possible speed. In case of a route error or collision with a marker cone, the trial was restarted after 40 seconds of rest. The participants performed five laps: one at low speed for route recognition; one at high speed; and three at maximum speed. For the analysis, the shortest time among the last three laps was considered.

Athletes with low and high FC scores were divided into two groups according to their ability or not to perform active elbow extension: Group 1 (G1) included the athletes with low scores (0.5 to 1.0) and Group 2 (G2) the athletes with medium and high scores (1.5 to 2.5).

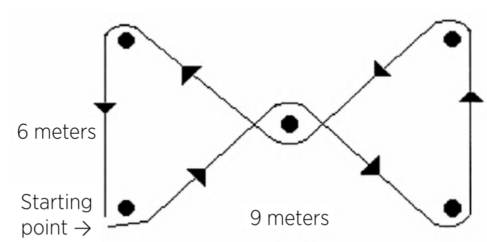


Figure 2. Zig-zag agility test route

Source: Gorgatti and Böhme[18].

Data analysis

The SPSS software version 26.0 was used. Descriptive statistics are presented as central tendency and dispersion. Normal distribution was assessed by the Shapiro-Wilk test. To analyze the relationship between muscle strength values and AT performance, Spearman's correlation was used. The t-test for independent groups was applied to identify differences in bilateral isometric strength for shoulder flexion, extension, and abduction, and elbow flexion, as well as for AT execution time between groups with different functional classifications. The significance level adopted was $p \leq 0.05$.

RESULTS

Muscle strength test

Table 1 presents the characterization of the performance of G1 and G2 athletes in the isometric strength test. Athletes with higher FC scores (G2) have higher shoulder extensor isometric strength compared with athletes with lower scores (G1) (p=0.001), with large effect magnitude (d=3.10).

Table 1. Isometric muscle strength test values for G1 and G2, expressed as mean and standard deviation

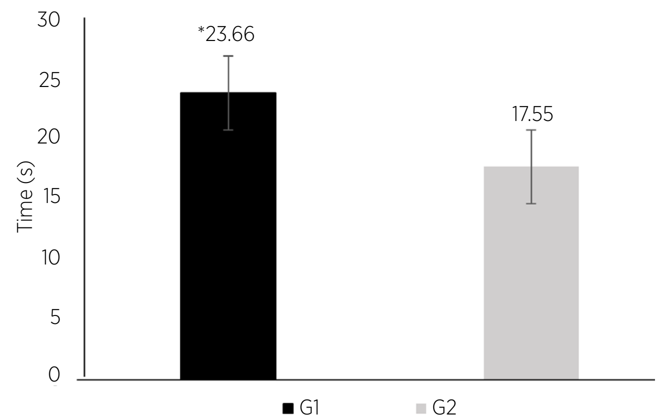
	G1 (FC: 0.5 and 1.0) G2 (FC: 1.5 to 2.5).	N	Mean (lbf)	Standard deviation
Bilateral shoulder flexion strength	G1	5	24.74	6.89
	G2	5	31.98	5.08
Bilateral shoulder extension strength	G1	5	29.60	5.19
	G2	5	44.64	4.46
Bilateral shoulder abduction strength	G1	5	26.42	4.20
	G2	5	27.64	4.97
Bilateral elbow flexion strength	G1	5	53.18	17.06
	G2	5	62.90	13.49
Bilateral elbow extension strength	G1	5	0*	0*
	G2	5	38.84	9.16

*Athletes without elbow extensor function.

lbf: pound-force.

Functional classification × Agility

The maximum execution time was 28.25 seconds, and the minimum was 16.15 seconds, while the mean time was 20.60±4.54s. G2 athletes performed the AT in less time compared with G1 athletes (p=0.01; d=2.00), according to Graph 1.



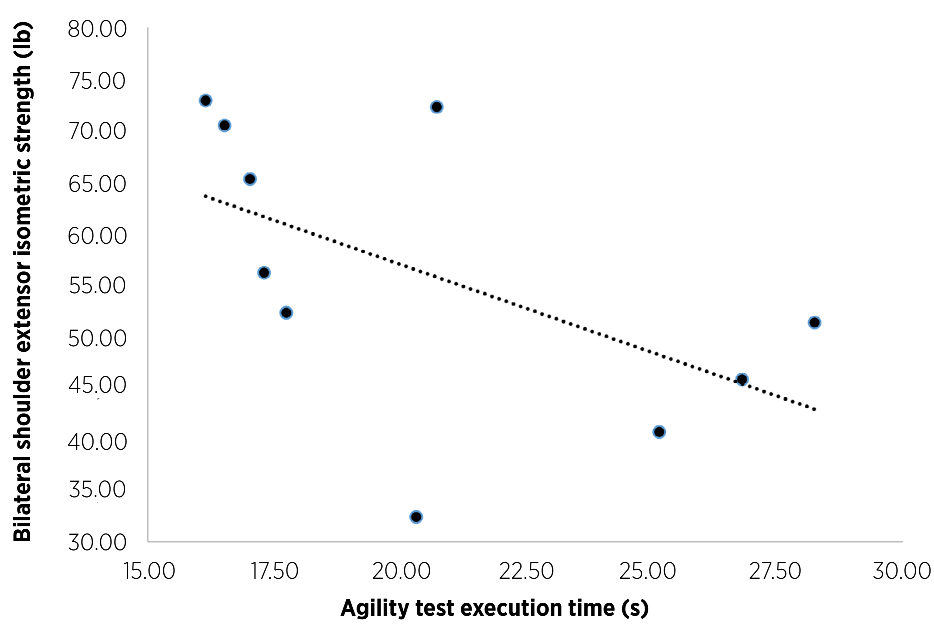
Graph 1. Comparison of the execution time of the zig-zag agility test between G1 and G2 athletes

*G1 (23.66±3.98)>G2 (17.55±1.64), p=0.01, d=2.00.

s: seconds.

Correlation between strength and agility

Graph 2 shows a negative correlation between agility test execution time and bilateral isometric shoulder extensor strength (p=0.019; r=−0.71). However, no group showed a correlation between AT execution time and bilateral isometric strength of shoulder flexors (p=0.67), shoulder abductors (p=0.58), elbow flexors (p=0.60), and elbow extensors (p=0.18).



Graph 2. Correlation between the result of the zig-zag agility test and bilateral shoulder extensor isometric strength

lb: pounds; s: seconds.

DISCUSSION

This study compared the agility of two groups of WR athletes—separated according to their FC score—and described the relationship between agility and upper extremity IMS. G2 athletes (FC=1.5, 2.0, and 2.5) were significantly more agile when performing the test than G1 athletes (FC=0.5 and 1.0). We observed a negative correlation between bilateral shoulder extensor IMS and AT execution time. These results show that athletes' performance is more influenced by the recovery phase, in which the shoulder extensor muscles reposition the hands to restart the cycle. This finding can guide coaches and physical therapists regarding the need for specific training to improve the performance of lower CF athletes in agility actions.

The biomechanics of the shoulder depends on the speed of the movement performed, so that the increase in angular acceleration for flexion/extension movements is proportional to the increase in the speed of the wheelchair propulsion gesture[19]. During wheelchair propulsion, the shoulder extensors have greater activation in the recovery phase. Moreover, the activity of the subscapularis muscle is higher in both the push and recovery phases. The triceps brachii long head, which also has a shoulder extensor function, has higher electromyographic activity in quadriplegic individuals[20].

In the AT, changes in direction demand high acceleration and braking capacity from the wheelchair, increasing the eccentric demand on the shoulder extensors, which act in the deceleration of both the upper extremity itself and the wheelchair. Considering these factors, the shoulder extensor muscles (mainly subscapularis and triceps surae long head) act in a compensatory way in WR athletes, promoting shoulder stability not only in the recovery phase, but also in the push phase, according to previous studies. Thus, the high eccentric demand of the AT may be one of the factors that justify the negative correlation found in the study, since athletes with greater isometric strength of this muscle group performed better on the test.

The better performances on the AT of athletes with higher FC scores corroborate the findings of the studies by Rhodes et al.[5] and Goosey-Tolfrey et al.[21]. Rhodes et al.[5], when evaluating the on-court mobility indicators of WR athletes, found that athletes with low HR scores spend less time on the court, reach a lower peak speed, and move at high speed for less time compared with athletes with high HR scores. Goosey-Tolfrey et al.[21] observed greater distance covered and less time spent in a sprint test among athletes with higher FC scores. This difference between athletes with high and low FC scores can be due to the great motor impairment in cervical spinal cord injuries, which reduces the variability of the athlete's motor response.

Regarding wheelchair propulsion techniques, Goosey-Tolfrey et al.[21] point that individuals with high scores perform the push phase more frequently and spend less time in that phase during wheelchair propulsion cycles. In another sport, Vanlandewijck et al.[19] observed the propulsion technique in relation to FC in 40 elite basketball athletes at different driving speeds and found no significant differences between FCs. However, although basketball and rugby are wheelchair sports, the physical and functional abilities of athletes in each are considerably heterogeneous.

Among the limitations of this study, the sample size stands out since, although it includes high-performance rugby athletes, it is small. We also highlight that muscle strength is only one of the factors that influence agility and that IMS may not fully reproduce the dynamic characteristics of wheelchair touch. Moreover, the strength tests were conducted with a handheld dynamometer by a trained evaluator; however, tools that do not require the application of force against the evaluator's resistance may provide more accurate measurements.

CONCLUSION

Athletes with higher FC scores are significantly more agile when performing AT. Moreover, isometric shoulder extensor strength showed a negative correlation with AT performance, showing that the greater the strength, the shorter the time needed to complete the test—and, thus, the better the agility in WR.

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REFERENCES

1. Silva A, Vital R, Mello MT. Atuação da fisioterapia no esporte paraolímpico. Rev Bras Med Esporte. 2016;22(2):157-61. doi: 10.1590/1517-869220162202154214.
2. Churton E, Keogh JW. Constraints influencing sports wheelchair propulsion performance and injury risk. BMC Sports Sci Med Rehabil. 2013;5:3. doi: 10.1186/2052-1847-5-3.
3. Osmotherly PG, Thompson E, Rivett DA, Haskins R, Snodgrass SJ. Injuries, practices and perceptions of Australian wheelchair sports participants. Disabil Health J. 2021;14(2):101044. doi: 10.1016/j.dhjo.2020.101044.
4. Silva AAC, Marques RFR, Pena LGS, Molchansky S, Borges M, et al. Esporte adaptado: abordagem sobre os fatores que influenciam a prática do esporte coletivo em cadeira de rodas. Rev Bras Educ Fis Esp. 2013;27(4):679-87. doi: 10.1590/S1807-55092013005000010.
5. Rhodes JM, Mason BS, Malone LA, Goosey-Tolfrey VL. Effect of team rank and player classification on activity profiles of elite wheelchair rugby players. J Sports Sci. 2015;33(19):2070-8. doi: 10.1080/02640414.2015.1028087.
6. Vanlandewijck Y, Theisen D, Daly D. Wheelchair propulsion biomechanics: implications for wheelchair sports. Sports Med. 2001;31(5):339-67. doi: 10.2165/00007256-200131050-00005.
7. Haydon DS, Pinder RA, Grimshaw PN, Robertson WSP. Overground-propulsion kinematics and acceleration in elite wheelchair rugby. Int J Sports Physiol Perform. 2018;13(2):156-62. doi: 10.1123/ijspp.2016-0802.
8. Akınoğlu B, Kocahan T. Characteristics of upper extremity's muscle strength in Turkish national wheelchair basketball players team. J Exerc Rehabil. 2017;13(1):62-7. doi: 10.12965/jer.1732868.434.
9. Roy JS, MacDermid JC, Orton B, Tran T, Faber KJ, et al. The concurrent validity of a hand-held versus a stationary dynamometer in testing isometric shoulder strength. J Hand Ther. 2009;22(4):320-7. doi: 10.1016/j.jht.2009.04.008.
10. Morrow MM, Rankin JW, Neptune RR, Kaufman KR. A comparison of static and dynamic optimization muscle force predictions during wheelchair propulsion. J Biomech. 2014;47(14):3459-65. doi: 10.1016/j.jbiomech.2014.09.013.
11. Hutchinson MJ, Phillips JLK, Mason BS, Goosey-Tolfrey VL, Beckman EM. Measures of impairment applicable to the classification of Paralympic athletes competing in wheelchair sports: a systematic review of validity, reliability and associations with performance. J Sports Sci. 2021;39(Suppl 1):40-61. doi: 10.1080/02640414.2020.1815957.
12. Mason BS, Altmann VC, Hutchinson MJ, Goosey-Tolfrey VL. Validity and reliability of isometric tests for the evidence-based assessment of arm strength impairment in wheelchair rugby classification. J Sci Med Sport. 2020;23(6):559-63. doi: 10.1016/j.jsams.2019.12.022.
13. Juul-Kristensen B, Bech C, Liaghat B, Cools AM, Olsen HB, et al. Assessment of shoulder rotation strength, muscle co-activation and shoulder pain in tetraplegic wheelchair athletes – a methodological study. J Spinal Cord Med. 2022;45(3):410-9. doi: 10.1080/10790268.2020.1803659.
14. Moon Y, Jayaraman C, Hsu IMK, Rice IM, Hsiao-Wecksler ET, et al. Variability of peak shoulder force during wheelchair propulsion in manual wheelchair users with and without shoulder pain. Clin Biomech (Bristol, Avon). 2013;28(9-10):967-72. doi: 10.1016/j.clinbiomech.2013.10.004.
15. Bossuyt FM, Hogaboom NS, Worobey LA, Koontz AM, Arnet U, et al. Start-up propulsion biomechanics changes with fatiguing activity in persons with spinal cord injury. J Spinal Cord Med. 2020;43(4):476-84. doi: 10.1080/10790268.2019.1582603.
16. Kolber MJ, Beekhuizen K, Cheng MSS, Fiebert IM. The reliability of hand-held dynamometry in measuring isometric strength of the shoulder internal and external rotator musculature using a stabilization device. Physiother Theory Pract. 2007;23(2):119-24. doi: 10.1080/09593980701213032.
17. Mason BS, Vegter RJK, Paulson TAW, Morrissey D, van der Scheer JW, et al. Bilateral scapular kinematics, asymmetries and shoulder pain in wheelchair athletes. Gait Posture. 2018;65:151-6. doi: 10.1016/j.gaitpost.2018.07.170.
18. Gorgatti MG, Böhme MTS. Autenticidade científica de um teste de agilidade para indivíduos em cadeira de rodas. Rev Paul Educ Fis. 2003;17(1):41-50. doi: 10.11606/issn.2594-5904.rpef.2003.138842.
19. Vanlandewijck YC, Spaepen AJ, Lysens RJ. Wheelchair propulsion: functional ability dependent factors in wheelchair basketball players. Scand J Rehabil Med. 1994;26(1):37-48. doi: 10.2340/1650197719942613748.
20. Mulroy SJ, Farrokhi S, Newsam CJ, Perry J. Effects of spinal cord injury level on the activity of shoulder muscles during wheelchair propulsion: an electromyographic study. Arch Phys Med Rehabil. 2004;85(6):925-34. doi: 10.1016/j.apmr.2003.08.090.
21. Goosey-Tolfrey VL, Vegter RJK, Mason BS, Paulson TAW, Lenton JP, et al. Sprint performance and propulsion asymmetries on an ergometer in trained high- and low-point wheelchair rugby players. Scand J Med Sci Sports. 2018;28(5):1586-93. doi: 10.1111/sms.13056.