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# Evaluating Deltoid Muscle Activation During Manual Wheelchair Propulsion in Parabadminton: Racket Effects and Intensity Levels

**Saulo F.M. Oliveira,[1] José Igor V. Oliveira,[2] Túlio L.B. Fernandes,[3] Marcelo C. Haiachi,[4] and Hanno Felder[5]**

[1]Movement, Sport and Rehabilitation Study Group, Department of Physical Education and Sports Sciences, Federal University of Pernambuco, Recife, PE, Brazil; [2]School of Physical Education, Universidade Estadual de Campinas, Campinas, SP, Brazil; [3]Institute of Physical Education and Sports, Federal University of Ceará, Fortaleza, CE, Brazil; [4]Department of Physical Education, Federal University of Sergipe, Aracajú, SE, Brazil; [5]Olympic Training Center Rhineland Palatinate/Saarland, Hermann Neuberger Sportschule, Saarbrücken, Germany

To compare the activation patterns of the shoulder muscles between 2 effort conditions, 8 participants without physical or motor impairment performed the Parabadminton-specific adapted shuttle run test in wheelchairs composed of 3 minutes moderately and intensely, under 2 counterbalanced conditions: with and without the racket. The electromyographic peak data of the anterior deltoid muscle (AD) and posterior deltoid muscle (PD) were collected and normalized by the maximum voluntary isometric contraction previously evaluated. The Wilcoxon test was used to compare conditions ($P < .05$). The AD showed lower activation during intense effort with the racket (153.76 vs 80.58; $P < .05$). It was observed that during effort with the racket, there was greater activation of the 2 portions of the deltoid during intense effort (AD: 50.36 vs 67.71; PD: 119.75 vs 148.09). Similarly, when analyzing the condition without a racket, greater activations for both portions of the deltoid muscle were observed for intense effort (AD: 46.70 vs 132.16; PD: 100.04 vs 191.51). It is observed that the use of rackets in Parabadminton in a wheelchair can decrease the pace of recruitment of muscle fibers of AD and PD.

***Keywords***: adapted shuttle run test, biomechanics, electromyography, paralympic sport

**Key Points**

- Shoulder muscle activation varied between effort conditions, with the anterior deltoid showing lower activation during intense effort with the racket compared to without.
- Both anterior and posterior deltoid muscles exhibited greater activation during intense effort, regardless of racket use, indicating increased neuromuscular demand in high-intensity conditions.
- Using a racket in Parabadminton may reduce the recruitment rate of anterior and posterior deltoid muscle fibers, potentially influencing performance and fatigue management in wheelchair athletes.

Badminton is one of the racket sports that has experienced significant growth in the last 10 years, culminating in its inclusion in the Tokyo 2020+1 Paralympic Games.[1] Para-badminton (PBd), a Paralympic sport, is divided into 6 sports classes, which differ by severity and type of impairment. Among the classes with the highest demand in PBd are those designed for athletes who compete in wheelchairs (WH1 and WH2).[2] Due to its unconventional and inefficient movement, manual wheelchair propulsion entails a series of muscle demands that can be harmful in the long term to athletes, leading to pain, discomfort, and injuries in the upper limbs, particularly affecting the shoulders, elbows, and wrists.[3] Most studies on muscle activation during manual propulsion gestures are conducted in a laboratory setting.[4–6] The repetitive nature of the propulsion gesture in a wheelchair, combined with the low mechanical efficiency for locomotion, is responsible for increased overload on the upper limbs.

S. Oliveira https://orcid.org/0000-0002-4402-1984
Fernandes https://orcid.org/0000-0002-6441-3205
Haiachi https://orcid.org/0000-0002-9361-9018
Felder https://orcid.org/0009-0001-3585-7501
J. Oliveira (igorvasconcelos200@hotmail.com) is corresponding author, https://orcid.org/0000-0002-0034-9638

When comparing 2 different manual propulsion techniques (traditional and "para-backhand"), electromyography data (EMGs) showed that the carpal radial flexor and triceps brachii were more active in the propulsion phase (traditional technique). The upper trapezius and the posterior-middle deltoid were more active in the ascending recovery phase, while the radial extensor of the carpus, the brachialis, the antero-middle deltoid, and the pectoralis major were more active during the descending recovery phase ("para-backhand" technique).[7] It is also known that from a biomechanical point of view, the impulse frequencies were similar between both directions of propulsion at all speeds studied.[5] The studies are still in their early stages; therefore, the information regarding EMGs during the manual propulsion of sports wheelchairs is limited.[8] The available information on these sports does not provide evidence that can be applied in the context of PBd.

When it comes to higher demand and overload, the shoulder region is the most affected by the continuous use of wheelchairs.[9] The glenohumeral joint, composed of several multiarticular muscles and stabilizers, may end up experiencing the highest incidences of pain, discomfort, and repetitive stress injuries.[10] In sports, the level of training and the variety of impairments eligible for each modality make it difficult to establish homogeneous patterns of predisposition. Regarding the biomechanical aspect of manual propulsion movement, the anterior and posterior portions of the deltoid are usually more involved in the forward and reverse displacement actions,[8,11] along with other muscles located in underlying joints. However, in PBd games of classes WH1 and WH2, successive front and back movements are often observed, requiring even more functionality from these specific muscles, including sudden stops and quick exits to regain position.

Some studies have been conducted to assess the impact of racket use on performance in wheelchair tennis.[12,13] In PBd, only one study has investigated these influences, focusing on spatiotemporal and kinetic parameters.[14] However, studies on EMGs related to information during manual propulsion of sports wheelchairs are still in their early stages. The information available in these sports does not provide evidence that can be applied in the context of PBd. Thus, the objective of this study was to compare the activation patterns of the deltoid muscle, including the anterior and posterior portions, in a standardized effort protocol simulating a specific action of PBd with and without the use of a racket. The hypothesis is that there will be differences in the EMG activity of the involved muscles depending on the use or non-use of a racket. Analyzing these aspects allows for a more comprehensive understanding of the challenges faced by PBd athletes moving in wheelchairs while holding a racket, providing insights for improvements in the sport and support for practitioners.

# Materials and Methods

## Experimental Approach to the Problem

The sequence of procedures adopted was as follows: (1) orientation of the research procedures and signing of the Ethics Committee agreement, (2) collection of sociodemographic data, (3) evaluation of maximum voluntary isometric contraction (MVIC) (presented in the sequence of topics), and (4) measurement of muscle activation during the specific effort of PBd. All experiments were conducted on a single day, and all participants had previous experience in using sports wheelchairs. The same wheelchair was used for all participants, with the tires calibrated to the maximum level (ie, fill the tires with air to the upper limit recommended by the manufacturer). The wheelchair used for basketball practice weighs 13 kg, has bold tires, and a camber angle of 15° (ALPHAMIX). Basketball chairs are permitted for use in official PBd games and are distinguished only by front bumper protection and a more elongated rear anti-tip. Initially, participants provided their sociodemographic information via a questionnaire, after which they were prepared for electrode placement on the skin. A counterbalanced procedure was implemented for the order of conditions. The chosen experimental conditions were 1 (“with racket”) and 0 (“without racket”). The same official steel racket, weighing 115 g and with dimensions of 66 cm × 20 cm × 3 cm (VOLLO), was used for all participants. Each participant performed both experimental conditions and repeated the effort test once for each condition. Before commencing the sequence of experiments, 10 minutes for warming-up and familiarization with the test was allowed. All procedures were conducted in the morning, and participants were instructed to maintain their normal diet and refrain from strenuous exercise 24 hours before the test.

## Participants

Eight participants (age: 23.5 [3.0] y; weight: 70.5 [8.5] kg; height: 172.5 [5.0] cm), without physical or motor impairment, were recruited for convenience to participate in the experiments. According to previous studies, we chose to use individuals without physical or motor impairment to standardize the sample, particularly when analyzing aspects that may impact manual propulsion capacity in wheelchairs.[14–16] Some forms of impairments require very specific adaptations in equipment and other accessories, which can significantly influence the type of experiment to be conducted. Furthermore, muscle activation may be an important indicator for the development of injuries. Experienced athletes with disabilities may have preexisting conditions of muscle instability and imbalance,[17,18] generating significant bias in initial descriptive studies. All procedures included in this investigation were approved by the first author’s Institutional Ethics Committee (Protocol no. 77083524.4.0000.5208) and adhered to the recommendations of the Declaration of Helsinki.

## Procedures

### Sociodemographic Data

Sociodemographic information for each athlete was collected using a questionnaire designed by researchers. The questionnaire included personal details (eg, age, height, and weight). All data were collected individually and controlled by the study’s main researcher.

### Measurement of Muscle Activity

All electrode placement procedures followed the recommendations of SENIAM (https://www.seniam.org/), with prior cleaning and shaving. After electrode placement, all assessed points were secured with elastic tapes and adhesives. Each participant received a unique kit containing electrodes, razors, alcohol wipes, and adhesive. Disposable surface electrodes (unipolar, MAXICOR Medical Products) with a low impedance of 25 mm in diameter and conductive solid cellulose gel were used. For data acquisition, the NewMiotool tool (MIOTEC Biomedical Equipment) was employed through the wireless device. The signal was recorded using the Miotec Suite software and stored on a laptop. The acquisition frequency was 1 kHz, and the data were smoothed by a third-order Butterworth filter. After converting the data into root mean square, a bandpass filter of 20–500 Hz and a notch filter of 60 Hz were applied to minimize interference from the electrical network. Muscle activity peaks were normalized by each participant’s individual MVIC, and the highest values recorded throughout the protocol were considered the maximum percentage of voluntary contractions for the analyses.

### The Measure of Maximum Voluntary Isometric Contraction

The present study focused on the deltoid muscle (anterior and posterior portions). For the evaluation of MVIC, the procedures described in previous studies were used, taking into account the nature and specificity of the muscles involved in the analysis.[19] The participants remained seated in wheelchairs and performed a sequence of 4 movements to evaluate the MVIC of the deltoid muscle: (1) shoulder abducted 90° in the plane of the scapula with internal rotation of the humerus and elbow extended, the arm abducted with resistance applied to the wrist; (2) shoulder abducted at 90° in the plane of the scapula with neutral humeral rotation and elbow flexed 90°, with the arm internally rotated with resistance applied to the wrist; (3) flexion of the shoulder 125° with resistance applied above the elbow and at the lower angle of the scapula, attempting to rotate the scapula with the participant sitting in an upright posture without support for the back; and (4) shoulders flexed 90° bilaterally with the hands together (resistance applied in one hand against the other), elbows flexed 20°, and arms adducted horizontally. Two repetitions (5 s of contraction and 7 s of interval between repetitions) were performed for each movement. At the end of the 4 movements, with the recording of the EMG signal of both portions of the deltoid, the highest signal recorded for each muscle was considered the individualized MVIC and automatically transferred to the profile of each participant.

### *Adapted Shuttle Run Test to Parabadminton*

A specific shuttle run task was performed by all participants. The task aims to evaluate the ability to move quickly forward and backward over a distance of 5 m marked by cones, which is a specific movement for PBd athletes.[20] The protocol used presents good internal consistency in the sample studied ($\alpha$-Chrombach = .737). Upon the evaluators' signal, the participants moved in a straight line toward the cone in front of them until touching the front wheel on a boundary line between 2 cones. After this movement, the athlete had to move by touching the chair backward toward their starting point. This same sequence was repeated by the participant in 2 consecutive conditions. In the first condition, they had to maintain the rhythm of the test sequence for 3 minutes at a moderate intensity (rate of perceived exertion [RPE] = 3–4), monitored by a RPE ranging from 0 to 10.[21] Before starting the effort protocol, still, in the familiarization period, all subjects went through a moment of presentation of the effort scale, with modifications in the speed of execution of the manual propulsion. This was necessary to ensure the maintenance of the intensity level. Then, after a rest period of 2 minutes, each participant performed the same test at the highest possible intensity (RPE = 7–9) for the same duration. The total distance covered in the highest intensity condition was considered as a measure of the test. To calculate the average speed in kilometers per hours achieved in the test, the following equation was used:

$$\text{AS (km/h)} = \left\{\frac{(\text{NT} \times 5)}{180}\right\} \times 3{,}6,$$

where NT is the number of turns (full cycles) of round trips, 5 is the distance traveled, 180 is the time in seconds of the complete test, and 3.6 is the speed correction factor in meters per second for kilometers per hours.

It is worth noting that the test was performed in the same way and with the same performance indicators in both conditions (with and without the racket).

## Statistical Analyses

The normality of the data was verified using the Shapiro–Wilk test. Nonparametric tests were chosen in the study. The conditions "with" and "without" racket and the conditions of the "moderate" and "intense" effort tests were considered as comparison criteria. Thus, the Wilcoxon signed-rank test was used, with Bayes correction to compare conditions. The same procedure was performed to compare the average speed reached between the conditions "with" and "without" racket. The JAMOVI software (version 2.3.28, JAMOVI) was used in all analyses, considering a significance level of .05 ($P < .05$).

# Results

Table 1 presents all participants' sociodemographic and performance data in the effort test.

Table 2 presents the descriptive data related to muscle activation of the anterior and posterior deltoid (PD) by percentages of MVIC of all participants.

Figure 1 shows the comparison of the average speed performance achieved in the adapted shuttle run test between the experimental conditions (with and without racket). It is observed that the condition "with racket" presented lower values of speed compared with the condition "without racket," with a mean difference of 0.25 seconds.

Figures 2 and 3 illustrate the results of the comparisons of deltoid muscle activation (anterior and posterior) between experimental conditions (with and without racket) and between effort intensities (moderate and intense), respectively. It was observed that a significant difference between conditions was only evident for the anterior deltoid (AD) during maximum effort, with the experiment involving a racket resulting in lower activation (153.76 vs 80.58, respectively; Figure 2, panel B). When comparing conditions based on intensity, it was noted that in the "with racket" scenario, there was greater activation of both portions of the deltoid during intense effort (AD: 50.36 vs 67.71; PD: 119.75 vs 148.09; Figure 3). Similarly, in the "without racket" condition, higher

**Table 1 Individualized Descriptive Information for Sociodemographic and Performance Data in the Adapted Shuttle Run Test**

| ID | Age, y | Weight, kg | Height, cm | BMI, kg/m$^2$ | NCWouR | NCWR | SpeedWouR, km/h | SpeedWR, km/h |
|---|---|---|---|---|---|---|---|---|
| 1 | 25 | 69 | 172 | 23.32 | 23 | 21 | 2.30 | 2.10 |
| 2 | 23 | 64 | 171 | 21.89 | 14 | 15 | 1.40 | 1.50 |
| 3 | 22 | 80 | 180 | 24.69 | 21 | 18 | 2.10 | 1.80 |
| 4 | 24 | 82 | 176 | 26.47 | 21 | 13 | 2.10 | 1.30 |
| 5 | 22 | 72 | 166 | 26.13 | 24 | 20 | 2.40 | 2.00 |
| 6 | 22 | 89 | 180 | 27.47 | 19 | 18 | 1.90 | 1.80 |
| 7 | 31 | 68 | 169 | 23.81 | 22 | 22 | 2.20 | 2.20 |
| 8 | 24 | 69 | 173 | 23.05 | 21 | 19 | 2.10 | 1.90 |
| M | 23.50 | 70.50 | 172.50 | 24.25 | 21.00 | 18.50 | 2.10 | 1.85 |
| SD | 3.00 | 8.58 | 5.01 | 1.93 | 3.07 | 3.01 | 0.31 | 0.30 |
| *P* | .357 | .647 | .791 | .006 | .099 | .670 | .010 | .670 |

Abbreviations: BMI, body mass index; M, mean; NCWouR, number of cycles completed without racket; NCWR, number of cycles completed with racket; SpeedWouR, average speed achieved without racket; SpeedWR, average speed achieved with racket. Note: *P* value (Shapiro–Wilk test of normality).

**Table 2 Individualized Descriptive Information for Deltoid Muscle Activation Data (Anterior and Posterior Portions) During the Adapted Shuttle Run Test**

| | With racket (%MVIC) | | | | Without racket (%MVIC) | | | |
|---|---|---|---|---|---|---|---|---|
| | Moderate | | Intense | | Moderate | | Intense | |
| ID | AD | PD | AD | PD | AD | PD | AD | PD |
| 1 | 45.14 | 178.00 | 81.41 | 247.44 | 62.25 | 269.84 | 166.08 | 332.19 |
| 2 | 104.96 | 194.43 | 173.69 | 232.57 | 119.62 | 224.33 | 369.18 | 655.65 |
| 3 | 34.26 | 27.07 | 59.16 | 89.76 | 23.64 | 16.20 | 608.69 | 81.24 |
| 4 | 85.00 | 126.00 | 68.84 | 142.42 | 52.66 | 118.94 | 85.05 | 271.60 |
| 5 | 24.27 | 113.50 | 66.58 | 411.63 | 52.66 | 118.94 | 209.51 | 243.99 |
| 6 | 55.57 | 168.38 | 48.87 | 124.72 | 30.89 | 81.15 | 58.77 | 120.63 |
| 7 | 13.76 | 93.48 | 60.23 | 102.60 | 38.79 | 63.92 | 98.23 | 107.56 |
| 8 | 61.84 | 99.37 | 96.93 | 153.76 | 40.75 | 58.19 | 80.58 | 139.03 |
| Mean | 50.36 | 119.75 | 67.71 | 148.09 | 46.70 | 100.04 | 132.16 | 191.51 |
| SD | 30.67 | 54.62 | 39.88 | 106.72 | 29.82 | 86.67 | 190.47 | 188.73 |
| *P* | .874 | .702 | .008 | .092 | .038 | .302 | .026 | .026 |

Abbreviations: AD, anterior deltoid; %MVIC, maximum voluntary isometric contraction; PD, posterior deltoid. Note: *P* value (Shapiro–Wilk test of normality).

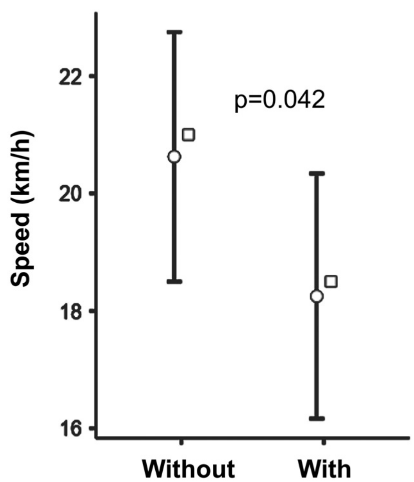


**Figure 1** — Speed performance comparison between the conditions of the adapted shuttle run test (with and without racket). Circle (mean); square (median).

activations for both portions of the deltoid muscle were observed during intense effort (AD: 46.70 vs 132.16; PD: 100.04 vs 191.51; Figure 3).

## Discussion

This study aimed to compare the activation patterns of the deltoid muscle, anterior and posterior portions in an adapted effort test simulating a specific action of PBd. The main finding of our results was that the activity of AD is influenced by the use of a racket when the intensity is maximum (Figure 2, panel B), whereas AD and PD are more activated, regardless of the use of rackets, of greater intensity compared with moderate effort (Figure 3). In addition, it was also found that the average speed calculated between the conditions with and without the use of rackets presented a significant difference, reinforcing the influence that the implementation has on the specific performance (Figure 1). These findings lead us to possible interpretations about the influence of the racket on the PBd performance.

This investigation marks the first attempt to examine muscle activation during specific simulated efforts in PBd. While other studies have explored the impact of rackets on performance, our focus was on the unique muscle activation patterns in PBd. In one study, the influence of rackets on spatio-temporal parameters was investigated, revealing that participants increased maximum total force but decreased the fraction of effective force with the dominant hand compared with the nondominant hand when using a racket.[14] In a different study, maximum speeds averaged 4.39 (0.74) m/s; however, they were reduced by 0.18 (0.06) m/s during racket conditions. Moreover, when spinning in racket conditions, the speeds achieved during the first 3 pushes were significantly diminished.[12] The decline in top speed and relative speed while holding a tennis racket may be attributed to an ineffective impulse technique, leading to low force application efficiency. The correlation between these parameters and trunk stability is also discussed.

From a spatio-temporal perspective, studies indicate that when propelling with a racket, the racket's side exhibits significantly lower impulse time, a reduced percentage of impulse time, a lower contact angle, greater power loss before and after the impulse, and a higher peak.[14,22] Similar significant differences were observed when comparing the same hand in the context of propulsion with and without a racket, or when analyzing sprint data. Propelling the wheelchair while holding a racket has adverse effects on propulsion technique and may result in upper extremity injuries. The increased time required to connect the hand with the racket to the hoop leads to elevated power losses and subsequently higher power generation during the shorter push phase.[14]

In a way, a greater increase in the activation of AD and PD during efforts with higher intensity compared to moderate efforts was anticipated. These findings can be attributed to the increased demand for recruiting muscle fibers to facilitate the acceleration of the wheelchair both forward and backward in a straight line and at a higher speed. It is noteworthy that the AD and PD muscles also play a stabilizing role in the glenohumeral joint. Thus, it should be acknowledged that the heightened muscle activation may also be linked to the necessity of stabilizing the joint during transitions in

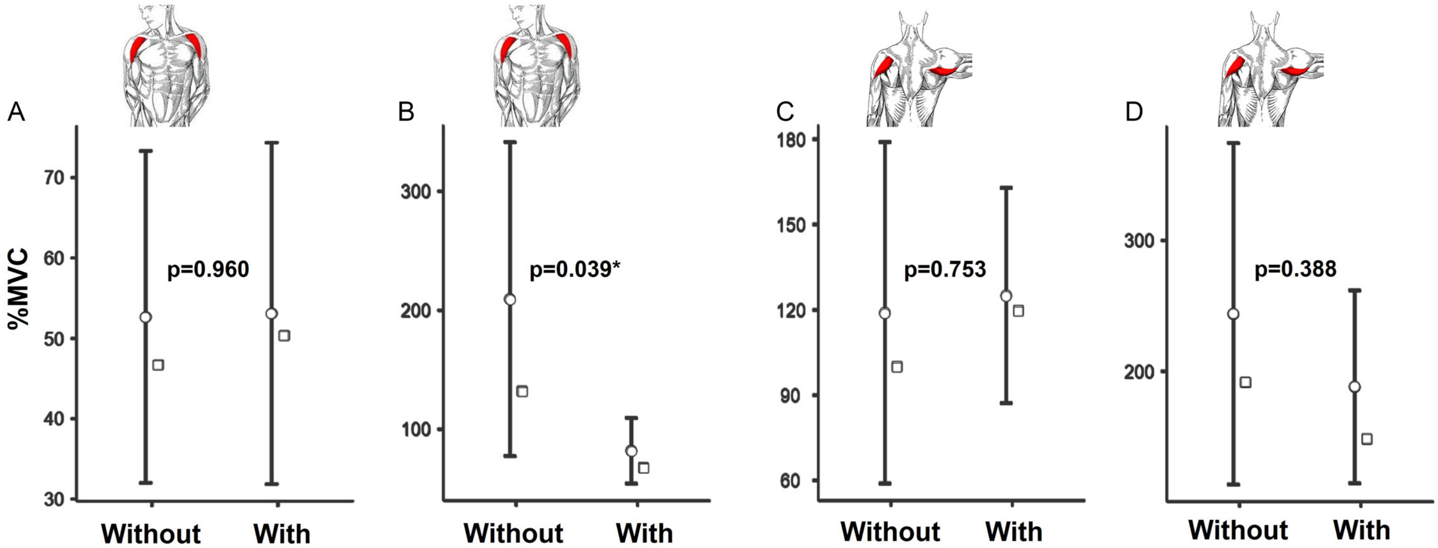


**Figure 2** — Comparisons of deltoid muscle activation (anterior and posterior portion) between conditions "with racket" and "without racket." Panel A and B, anterior portion (moderate and intense effort, respectively); Panel C and D, posterior portion (moderate and intense effort, respectively). Circle (mean); square (median). MVC indicates maximum voluntary isometric contraction. $^{*}P < .05$.

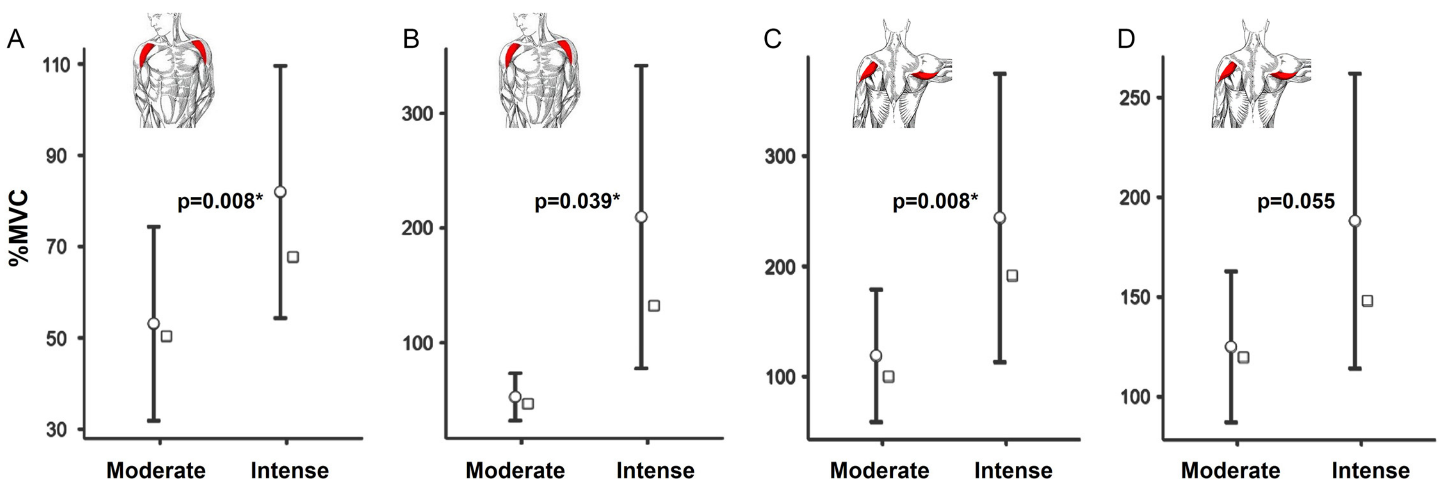


**Figure 3** — Comparisons of deltoid muscle activation (anterior and posterior portion) between "moderate" and "intense" effort conditions. Panel A and B, anterior portion (conditions with and without a racket, respectively); Panel C and D, posterior portion (conditions with and without a racket, respectively). Circle (mean); square (median). MVC indicates maximum voluntary isometric contraction. $^{*}P < .05$.

the front–back movement. Other studies have similarly identified increased shoulder activations in response to greater fiber recruitment required to propel the wheelchair during more challenging maneuvers,[23,24] contingent upon the specific configuration of the wheelchairs.[6]

Reverse propulsion can serve as a strategy to alleviate discomfort in the shoulder region for wheelchair users,[25] and one of the crucial muscles for this movement is the PD. In our study, we observed that the magnitude of peak activation in PD consistently remained lower than that demonstrated by AD. These discrepancies may indicate a mechanical disadvantage in executing the manual propulsion gesture, as a portion of the forward impulse to sustain acceleration in the wheelchair is likely contributed by other muscles, such as the triceps, biceps, and even the trunk region. Nevertheless, despite an apparent reduction in muscle recruitment with racket use (Figure 3), there was no significant change in PD activation.

It appears that higher effort intensities together with more challenging tasks are aligned with greater activation of the shoulder muscles in manual wheelchair propulsion. In a study of 12 experienced wheelchair users,[26] increased RPE was demonstrated postfatigue activity, with no significant changes in forces exerted, but increased forward thoracic tilt and range of motion. Musculoskeletal activation showed increased glenohumeral joint contact force and postfatigue muscle forces. These findings suggest a potential link between fatigue, altered propulsion technique, and increased shoulder loading, highlighting the risk of overuse injuries. As previously mentioned, the muscles of the glenohumeral joint serve primarily to maintain joint stability. Only in conditions of greater instability in manual propulsion is there greater activation of the deltoid muscles.[27] The proposed activity (adapted shuttle run), although intense, had a more stable character considering the movement of the volunteers, especially in the lateral dimensions.

This study has certain limitations. First, the recruitment of individuals without physical or motor impairment, while commonly employed in scientific studies on manual wheelchair propulsion, may differ to some extent from the realities observed in Paralympic sports, their specific sports classes, and the types of impairment encountered. Between classes WH1 and WH2, trunk control is the variable used to prioritize athletes in the functional classification. However, both classes of athletes maintain their shoulder muscles (deltoid) preserved for manual propulsion, otherwise, they would not be able to practice the sport with autonomy, dexterity, and intensity. Therefore, we believe that the limitation lies only in the comparison of results, but not in the presentation of activation responses at the level of the muscles analyzed. Another limiting factor is that the specific effort test solely considers the average speed of the route, whereas the propulsive gesture in the game is intense at various times. Future studies should concentrate on conducting tests at shorter distances and also take into account variables, such as maximum speed and synchronization with spatio-temporal parameters. Nevertheless, the highlighted limitations do not diminish the significance of our findings. This study is the first to investigate muscle activation (ie, examined peak EMG values) in PBd, simulating a game action. Despite potential factors that could influence results across diverse samples, particularly in experienced athletes, our findings provide valuable benchmarks for similar studies aimed at preventing shoulder injuries and establishing training loads for PBd athletes in wheelchairs.

## Conclusions

From a practical standpoint, this study highlights significant considerations on 2 main fronts. First, regarding the use of a racket during the manual propulsion gesture in PBd, it is deemed essential but necessitates skill and adaptation from the athlete. Once the athlete is fully adapted to optimal equipment, the opportunity arises to achieve the best possible technical outcomes. However, a potential reduction in muscle activation, particularly during more intense movements, may lead to discrepancies between the dominant and nondominant limbs, given the significant reduction in AD activation during forward propulsion. This imbalance could, over time, elevate the risk of developing injuries on the contralateral limb. The second consideration pertains to alterations in the level of activation of both muscles (AD and PD) from moderate to intense effort. This heightened recruitment of muscle fibers indicates a substantial load on the shoulder joint, significantly amplifying the risk of injuries due to excessive strain within a short duration. To mitigate this, introducing warm-up and preparatory activities before games and training sessions could be beneficial in conditioning the joints for repetitive and high-intensity gestures over a short timeframe.

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