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Effectiveness of Rehabilitation through Kinematic Analysis of Upper Limb Functioning in Wheelchair Basketball Athletes: A Pilot Study

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Abstract: Wheelchair basketball is one of the most popular Paralympic sports, including players with different diagnoses. To date, there is scarce evidence on shoulder functionality in wheelchair basketball players, and there is no consensus on a shoulder injury prevention program in these athletes. Therefore, in the present pilot study, we aimed to evaluate the effects of a comprehensive rehabilitative approach on shoulder ROM, muscle activity, and functioning in wheelchair basketball athletes. We included adult wheelchair basketball athletes playing in the Italian Second League who completed an 8-week comprehensive rehabilitative program, based on education to avoid upper limb pain injuries, preventive exercises, and improvement of ergonomics through kinematic analysis. We administered the Wheelchair User's Shoulder Pain Index (WUSPI) and the Kerlan-Jobe Orthopaedic Clinic (KJOC) questionnaire to evaluate pain experienced during functional activities, and used kinematic analysis integrated with sEMG to evaluate shoulder function and propulsion pattern. A sample of 10 wheelchair athletes (33.75 ± 6.42 years) were assessed. After the intervention there was a significant ($p < 0.05$) difference in WUSPI score (27.0 ± 18.5 vs. 25.0 ± 21.5) and in KJOC score (89.3 ± 10.4 to 95.4 ± 9.1). Moreover, there was a significant improvement in scapular upward rotation, abduction, and extra-rotation of the glenohumeral joint. Propulsion techniques improved in pattern and acceleration. This approach played a key role in improving upper limb function, reducing the incidence of pain and cumulative trauma disorders. However, the small sample size could affect the generalizability of results. In conclusion, healthcare professionals should monitor wheelchair athletes, assessing the patient's function, ergonomics, equipment, and level of pain, and introducing specific exercises to prevent upper limb injuries.

Keywords: rehabilitation; biomechanics; shoulder; upper limb; wheelchair; basketball

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Citation: Demeco, A.; de Sire, A.; Marotta, N.; Palumbo, A.; Fragomeni, G.; Gramigna, V.; Pellegrino, R.; Moggio, L.; Petraroli, A.; Iona, T.; et al. Effectiveness of Rehabilitation through Kinematic Analysis of Upper Limb Functioning in Wheelchair Basketball Athletes: A Pilot Study. *Appl. Sci.* **2022**, *12*, 2929. https://doi.org/10.3390/app12062929

Academic Editor: Maciej Janeczek

Received: 16 February 2022
Accepted: 6 March 2022
Published: 13 March 2022

1. Introduction

Paralympic sports have gained great popularity and made a positive impact on mental health and physical fitness in recent years [1]. However, the overall prevalence of injuries is high [2], with a 1-year prevalence of severe injuries of 31% [3], of which 91% occur during training and 9% in competition [3].

Wheelchair basketball is one of the most popular Paralympic sports, including players with different diagnoses (spinal cord injury—SCI, cerebral palsy, polio, and spina bifida) and different levels of motor impairment due to their disability [4,5]. Repetitive movement and throwing with arms overhead are responsible for shoulder disorders in these patients [6]. Upper limb overstress due to daily and work activities could lead to a high prevalence of shoulder pain in people using a manual wheelchair [6]. Significant pain requiring analgesic medication is present in between 41% and 49% of wheelchair users, and is correlated with a lower quality of life [6]. In this context, the Consortium for Spinal Cord Medicine developed guidelines for the preservation of the upper limb function in people with SCI, reporting the crucial role that ergonomics might play in wheelchair users [6]. In fact, ergonomics, consisting of a multidisciplinary approach to optimizing the interaction between the user and their equipment to maximize the efficiency, safety/health, comfort, and performance of tasks was able to reduce the incidence of pain and cumulative upper limb trauma disorders in various settings [7].

Indeed, a wheelchair user is strongly recommended to minimize the frequency and force of upper limb tasks, avoiding potentially injurious positions at all joints as a strategy for preserving shoulder function while propelling the wheelchair during daily life activity [8].

Sports are known to have a positive impact on wheelchair users, as a result of constant physical and cognitive training [9]. In particular, exercise increases bone and muscle mass, counteracting disuse atrophy, and protects the skeletal muscle against oxidative stress and proteolysis [9]. Notably, exercise has neuroprotective properties, and regenerative and rehabilitative properties at both biochemical and physical levels [10]. However, wheelchair users participating in overhead sports are twice as likely to develop rotator cuff injures than their non-sport counterparts [11]. Pain is particularly relevant for wheelchair athletes, who experience shoulder problems at least once in their lifetime in up to 72–76% of cases [12]. The most common pathologies associated with shoulder pain in wheelchair athletes are: shoulder impingement syndrome, biceps tendinopathy, rotator cuff tears, and glenohumeral instability, with a dynamic component that can be highlighted by clinical examination and dynamic tests rather than by the usual imagery techniques that remain essentially static [12,13]. The consequences of injury for an adaptive athlete might extend well beyond exclusion from sport, potentially limiting functional independence and the ability to carry out routine daily activities and should be adequately treated [13,14]. However, shoulder disorders in wheelchair athletes have multifactorial causes such as range of motion (ROM) and strength imbalances which could be difficult to identify [4,11]. Indeed, kinematic alteration of the shoulder, overuse, and inefficient propulsion can all be responsible for the appearance of shoulder pain [8].

To date, there is scarce evidence on shoulder functionality in wheelchair basketball players, and there is no consensus on a shoulder injury prevention program in these athletes. A recent systematic review classifies the overall quality of the included studies as low, highlighting the need for a biomechanical investigation of different athletic tasks [4].

In these cases, surface electromyography (sEMG) and kinematic analysis might represent a valid and reliable tool for shoulder functional analysis [15,16], providing useful data on shoulder range of motion and muscle excitation [17].

Thus, longitudinal observational studies are needed to better investigate the effects that rehabilitation might have on improving upper limb function in these subjects [12].

In this context, this study aimed to evaluate the effects of a comprehensive rehabilitative approach on shoulder ROM, muscle activity, and functioning in a sample of male wheelchair basketball athletes.

2. Materials and Methods

2.1. Participants

In this pilot study, we recruited study participants from among an entire wheelchair basketball team playing in the Italian Second League. The study was performed during the regular season of 2018/2019. Inclusion criteria were: (1) age >18 years; (2) playing competitive wheelchair basket at national or international level as their full-time occupation; (3) subjects with 5 years or more of experience in the junior leagues; (4) subjects that had signed an informed consent form. Participants were excluded if: (1) they suffered from a traumatic shoulder injury that required surgical intervention and/or systemic inflammatory disease; (2) they had been included in any shoulder prevention program in the previous 6 months; (3) there were signs of impingement (using the Neer test, Hawkins–Kennedy test, and painful arc test). The examiners were instructed to protect the privacy of the subjects. The study was compliant with the Declaration of Helsinki and approved by the local Institutional Review Board. We followed the STROBE reporting guidelines.

2.2. Intervention

Study participants underwent a comprehensive rehabilitative program for improving upper limb function including: (a) general recommendations about the risk of upper limb pain and injury; (b) improvement of ergonomics, by modifying task performance; (c) instructions for the athletes to minimize the frequency and power required to complete upper limb activities; (d) instructions for the athletes to minimize potentially injurious positions of the upper limb (avoiding extreme wrist and shoulder positions); (e) instructions for the athletes to use long and fluid thrusts using the semicircular model; (f) flexibility exercises to improve/maintain a full range of glenohumeral joint movement focused on the pectoral and front shoulder muscles; (g) stretching exercises for the upper limb muscles; and (h) strengthening exercises using an elastic band, paying attention to shoulder depressors and scapular stabilizer groups during the exercises (see Figure 1). Warm-up before training or competition consisted of an 8-week protocol of 4 sessions/week under the supervision of a physical therapist with 10 years of expertise regarding wheelchair athletes.

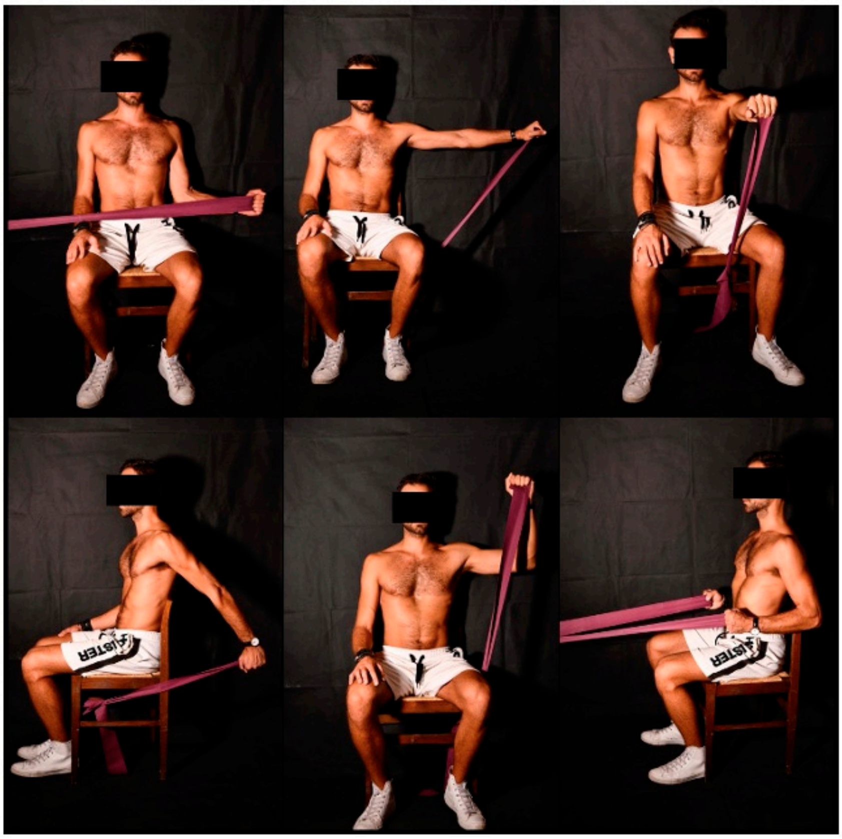

Figure 1. Exercise protocol with elastic band, consisting of external rotation, abduction, flexion, extension, and pulley exercises to improve the strength of the rotator cuff.

2.3. Functional Outcome Measures

We assessed the following outcomes before (T0) and after the intervention (T1): shoulder pain experienced during functional activities, using the Wheelchair User's Shoulder Pain Index (WUSPI); and the functional status of the upper extremities in overhead athletes, through the Kerlan-Jobe Orthopaedic Clinic shoulder and elbow score (KJOC score) [18].

2.4. Kinematic Analysis

A kinematic analysis using an optoelectronic system with infrared cameras (BTS Bioengineering S.p.A., Garbagnate Milanese, Milano, Italy) was performed on the wheelchair basketball players. A total of 11 reflective markers (9.5 mm diameter) were used, positioned at body reference points [19,20] (see Figure 2 for further details): Acromion, spine, scapula, humerus, forearm, wrist, and five sEMG wireless electrodes (BTS Bioengineering S.p.A., Garbagnate Milanese, Milano, Italy) on the following muscles: pectoral major, deltoid, trapezius, serratus anterior, and teres minor. The ROMs of both shoulders were compared during flexion, abduction, extension, and internal and external rotation, calculating any difference in the scapular movement angle, and at the same time evaluating the sEMG signals of the main muscles involved in the shoulder movement during throwing (see Figure 2) [21–23].

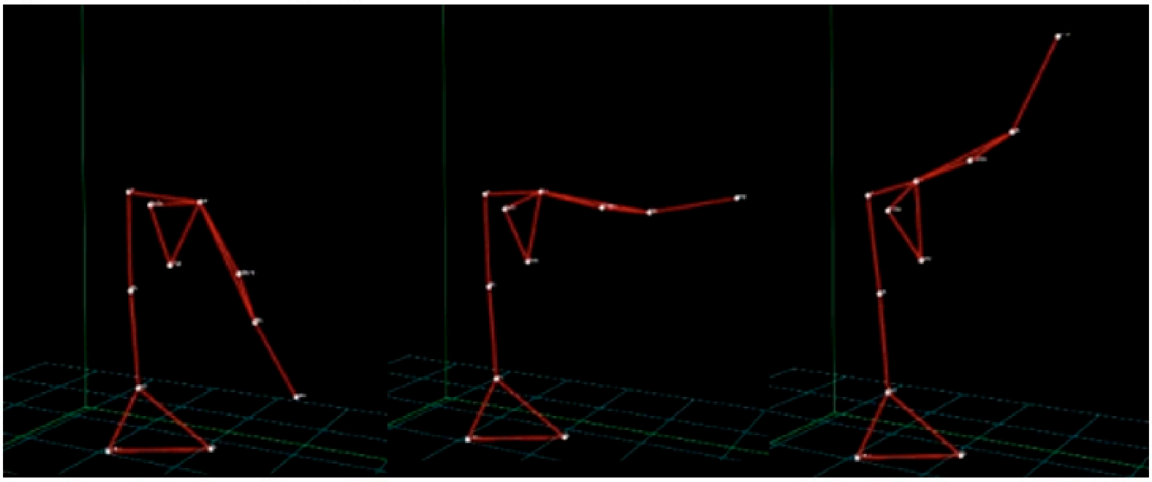

Figure 2. Kinematic functional analysis protocol for the shoulder showing 3 consecutive frames of the abduction movement of an athlete. A total of 11 reflective markers (9.5 mm diameter) were positioned at body reference points, as follows: processus spinosus of the seventh cervical (C7), eighth thoracic (T8), and second lumbar vertebra (L2), the acromion process (AC), center of the humerus diaphysis (Hm), lateral epicondyle (EL), ulnar styloid (US), trigonum scapulae (TS), inferior angle of the scapula (AI), and posterior superior iliac spine (Clsup).

We asked all participants to perform maximum flexion, extension, abduction, and internal and external rotation movements, first with the dominant limb and then with the non-dominant limb. The investigator provided instructions to the participants and demonstrated the correct plane of elevation before data collection. Participants were asked to complete the elevation and lowering phases in a controlled manner, aiming to accomplish each phase of the movement (elevation and lowering of the shoulder) in three seconds. If participants performed the movement in a different plane the test was discarded, and a new trial registered. Wheelchair basketball participants were seated in a dedicated chair, allowing participants to hold their arms by their sides in a neutral unobstructed position.

Before performing electromyography, the skin surface was shaved at the electrode sites, gently abraded, and cleaned with alcohol to reduce skin impedance. The surface electrodes were positioned according to the sEMG for Non-Invasive Assessment of Muscles (SENIAM) recommendations [24].

The raw EMG data were digitally filtered at a frequency bandwidth between 20 and 500 Hz, and the linear envelope EMG integrated activity was calculated to represent the amplitude values of the EMG signals.

The normalization process was performed according to the maximal voluntary isometric contractions (MVICs). We recorded the sEMG signals for the entire duration of each movement and calculated root mean square (RMS) values.

Moreover, the acceleration for each propulsion was analyzed on a standard system made of a wheelchair training roller and an inertial measurement unit [25,26]. The difference between the mean stroke acceleration at T0 and T1 (a_{T1}-a_{T0}) and the bilateral symmetry ratio (sym) between the dominant arm and non-dominant arm were calculated, where, in the latter case, a value ranging between 45 and 55% indicates symmetry, whereas a value lower than 45% or higher than 55% reflects greater accelerations for the non-dominant or dominant side, respectively [27].

The propulsion pattern was calculated as the mean of the push trajectory. The length of the trajectory and the area under the curve were obtained to calculate the area/perimeter ratio (APR) as an index of smoothness.

2.5. Statistical Analysis

Data management and analyses were conducted according to a pre-specified statistical analytical plan. Statistical analysis was performed using Stata v. 12 (StataCorp LP, College Station, TX, USA). Continuous variables are presented as means ± standard deviations. Normality was tested using the Shapiro–Wilk normality test. Significance was tested with the paired sample *t*-test, and a p value < 0.05 was considered to be statistically significant.

3. Results

Of the 15 male professional wheelchair basketball athletes, 10 athletes, with mean age 33.75 ± 6.42 years, met the eligibility criteria (Figure 3). They spent 7.13 ± 0.75 h playing basketball per week and 4.00 ± 1.63 h training per week. The 10 study participants suffered from lower limb amputations (n = 4), spinal cord injuries (n = 2), spina bifida (n = 1), cerebral palsy (n = 1), rickets (n = 1), and osteogenesis imperfecta (n = 1).

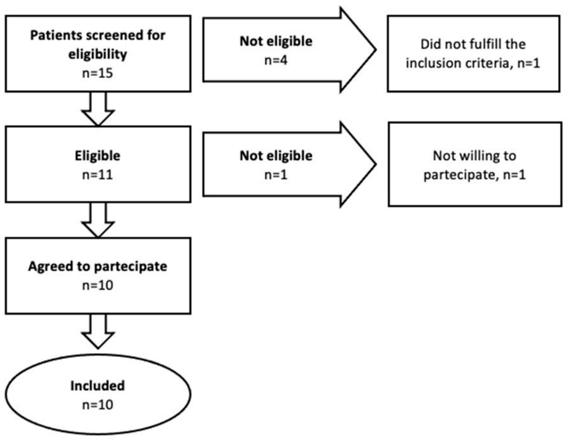

Figure 3. Flowchart of the recruitment process.

Both clinical outcome measures significantly improved after the intervention: the WUSPI score from 27.0 ± 18.5 to 25.0 ± 21.5 (p = 0.009), and the KJOC score from 89.3 ± 10.4 to 95.4 ± 9.1 (p = 0.026).

At T0, we found a significant difference between the dominant and non-dominant side for scapular upward rotation (p = 0.009) and glenohumeral abduction during scapular plane humeral elevation (p = 0.001). The study participants had a significant improvement in scapular upward rotation (p < 0.001), abduction (p < 0.001), and external rotation (p = 0.001) of the glenohumeral joint after the treatment. Extension, flexion, and internal rotation did not show significant differences ($p > 0.05$) (see Table 1 for further details).

Table 1. Differences in range of motion (degrees) of the scapulothoracic and glenohumeral joints before (T0) and after the 8-week intervention (T1).

		T0	T1	*p*-Values
Scapulothoracic joint				
Abduction	Dominant	33.30 ± 7.57	36.00 ± 7.77	0.018 *
	Non-dominant	39.20 ± 4.78	42.01 ± 8.56	0.031 *
Extension	Dominant	30.20 ± 11.14	33.30 ± 9.32	0.023 *
	Non-dominant	29.20 ± 14.49	32.40 ± 18.16	0.015 *
Glenohumeral joint				
Abduction	Dominant	123.60 ± 33.35	147.50 ± 16.20	0.007 *
	Non-dominant	110.20 ± 32.14	132.00 ± 23.12	0.019 *
Extension	Dominant	72.70 ± 11.08	80.60 ± 9.99	0.093
	Non-dominant	75.10 ± 9.45	78.50 ± 3.03	0.402
Flexion	Dominant	133.00 ± 20.58	131.30 ± 22.24	0.901
	Non-dominant	147.00 ± 22.14	156.00 ± 5.16	0.335
External rotation	Dominant	70.40 ± 11.39	80.20 ± 12.04	0.007 *
	Non-dominant	54.40 ± 14.21	77.10 ± 20.72	0.021 *
Internal rotation	Dominant	78.30 ± 14.91	82.20 ± 13.10	0.564
	Non-dominant	77.30 ± 14.23	86.70 ± 14.85	0.191

Means ± standard deviations for continuous variables. * = $p < 0.05$.

In particular, we found a statistically significant reduction in the contribution of the deltoid (32.41 ± 15.73 at T0 vs. 28.33 ± 9.25% of MVIC at T1; $p = 0.042$), and an increase in the contribution of the teres minor (4.28 ± 3.61 at T0 vs. 6.35 ± 3.48% of MVIC at T1; $p = 0.029$) and serratus anterior (29.29 ± 17.58 at T0 vs. 36.48 ± 25.73 at T1; $p = 0.037$) during the abduction of the upper limb movement. The pectoralis major (11.61 ± 10.87 at T0 vs. 10.04 ± 9.18% of MVIC at T1) and trapezius (21.37 ± 29.38 at T0 vs. 18.63 ± 25.47% of MVIC at T1) did not show significant differences ($p > 0.05$).

The propulsion pattern showed an improvement of the APR (0.066 ± 0.054 cm at T0 vs. 0.084 ± 0.059 at T1; $p = 0.002$) (Figure 4). Moreover, there was an average improvement of 4.8 ± 3.2% in the acceleration for a single stroke from T0 to T1 and a significant improvement in sym (43.55 ± 8.64 at T0 vs. 46.12 ± 11.92 at T1; $p = 0.031$).

Figure 4. Mean of the stroke patterns in the athletes at the baseline (red line) and at the end of treatment (green line). The area/perimeter ratio was 0.066 at T0 and 0.084 at T1.

4. Discussion

In the present study, we aimed to evaluate the impact of a comprehensive rehabilitative program on shoulder ROM, muscle activity, and functioning in a cohort of wheelchair basketball athletes. Functional shoulder alterations found in wheelchair basketball athletes in this study might reflect similar patterns in traditional overhead athletes [11]. The WUSPI index was used to detect even small levels of shoulder pain through a variety of specific functional activities for wheelchair users. The WUSPI index showed a lower value in athletes than non-athletes due to the positive impact of sport in daily life [28,29]. Sport helps people with disabilities to overcome their disabilities more easily, increasing their motivation and functional level [29]. On the other hand, long duration of training and an intense competition program could increase the injury rate and decrease the KJOC [30] index, due to the continuous excessive use of the shoulder [31].

For wheelchair users sport participation is important, as physical activity has many benefits such as psycho-physical well-being and the reduction of fat mass, avoiding obesity [11,29,32]. However, a balance is needed between enjoying the benefits of physical activity and the risk of shoulder overload [4]. This is an interesting challenge in competitive sport, in which a high stress on the joint due to repetitive technical gestures, the pressing rhythm of training, and trauma during the match increase the risk of injury. Therefore, it is important to make an early diagnosis of kinematic alteration to develop a specific prevention program [4]. In this context, kinematic analysis might be an optimal diagnostic option for adequately assessing upper limb functioning, as shown also in patients affected by other diseases [16].

To plan and schedule a preventive intervention to avoid the appearance of chronic pain, a kinematic analysis was performed at baseline for each athlete for a bilateral comparison of the kinematics of the shoulder in wheelchair basketball players, which showed that the scapula in the dominant side has reduced upward rotation compared to the non-dominant side. This could be related to the development of shoulder impingement syndrome, as a reduction in upward rotation of the scapula is associated with a reduction in the subacromial space and compression of the tendon of the rotator cuff, confirming that repetitive action with the arm overhead in wheelchair basketball athletes increases the risk of shoulder impingement [33]. Non-dominant glenohumeral ROM was lower than in the dominant side, due to the shortening of the glenohumeral ligaments caused by repetitive microtrauma and shoulder overuse, since each athlete uses the non-dominant side for wheelchair control during the game and in daily life [8,34]. The results at the end of treatment indicated a significant increase in upward scapular rotation movement and an increase in abduction and external rotation of the glenohumeral joint (as reported in Table 1). According to Wilroy et al. [11], this improvement in the scapula and shoulder ROM could be determined by the exercise program performed and is linked to a reduction in shoulder pain.

Moreover, the stress on the shoulder during wheelchair propulsion could also cause degeneration and injury of the rotator cuff [35]. This is particularly relevant in wheelchair athletes, especially those with SCI, who are predisposed to a muscle imbalance of the kinetic chain of the spine and upper limb and selective muscle weakness resulting in scapular dyskinesia, which represent potential risk factors in the development of shoulder injuries [4,14,35,36].

A change in the activation pattern of the shoulder girdle muscle, such as hyperactivation of the deltoid, attracts the head of the humerus, resulting in a reduction in the subacromial space. The reduction in the deltoid muscle contraction and the increase in the activity of the teres minor and anterior serratus obtained at the end of the treatment proposed (T1) could counteract the upward migration of the humeral head and increase joint stability. This contributes to improving the shoulder biomechanics and dynamic stabilization of the humerus in the glenoid, which is very important for the prevention and treatment of shoulder rotator cuff impingement syndrome [33].

Ergonomics plays an important role in minimizing the frequency and strength needed to complete upper limb activities and to avoid extreme or potentially harmful positions in all joints during wheelchair propulsion. Numerous studies have reported propulsion kinetics and kinematics and have suggested several ways to improve propulsion efficiency [7,37]. For this reason, wheelchair athletes were trained to improve efficiency through long and fluid propulsion strokes [6,14].

To quantify the smoothness of movement, we used the APR, a mathematical measure of the relationship between the area and the perimeter of a regular geometric figure. The APR is maximum for a circle. Generally, for the same perimeter of a regular polygon, the greater the number of sides, the greater the area. As a result of analyzing the most common propulsion model, the semicircle is the recommended model because it offers some biomechanical advantages compared to the other model and therefore could reduce the risk of shoulder injuries [8]. It also has the highest APR. Thus, at T1, the increase in APR indicates a propulsion model with a more regular propulsion stroke, with no sudden changes of direction and no extra hand movement. The optimization of the thrust arc can determine the best balance between peak force and task repetition.

To estimate the efficiency, the acceleration of a single stroke was used. Within each propulsion stroke, significant braking moments and power loss are generated. If $F = ma$, and m is a constant because a standard system was used, a higher acceleration at T1 means that the resultant of the force applied to the wheel is higher, because the wasted vector of force is less, and the stroke pattern is more efficient. This is consistent with the results of a study by Kwarciak [37], who found that the semicircular pattern (under-rim stroke) resulted in smaller negative deflection in axle moment.

Considering the symmetry ratio (sym), an average score of less than 45% at T0 is indicative of a preference for the non-dominant hand during wheelchair acceleration, which can contribute to the development of shoulder injuries. At T1, a sym of between 45 and 55% is the result of better coordination during the stroke cycle. The significant improvements in APR, acceleration, and sym showed that athletes had changed their propulsion technique, and had a more fluid, efficient, and symmetrical push mode.

Therefore, our results showed that shoulder injury prevention might be accomplished by performing exercises that improve flexibility and strength, and wheelchair athletes can achieve the goal of improving the range of shoulder movements to prevent injury [6,14,33,34].

The present study is not free from limitations. Firstly, the small sample size and the lack of a control group could affect the results and the generalizability of the results, with a potential overestimation of the outcomes. Secondly, sEMG measurements could present artifacts due to muscle crosstalk, although we tried to minimize this by considering and carefully selecting the appropriate electrode size, inter-electrode distance, and locations for electrode placement. Study participants were recruited from a local adapted sports team. Moreover, in this study we did not consider ultrasound as an examination tool [38] for muscle and tendons. Lastly, the small team size and inclusion–exclusion criteria limited the number of eligible participants. Further studies are needed to improve the generalizability of the results, including a larger sample size and a control group.

5. Conclusions

A global rehabilitative approach based on education to avoid upper limb pain injuries, training, and improvement of ergonomics through kinematic analysis, was shown to play a key role in improving upper limb function in male wheelchair basketball players. This approach might reduce the incidence of pain and cumulative trauma disorders of the upper limb, starting from an adequate assessment of the patient's function, ergonomics, equipment, and level of pain. Thus, we strongly encourage healthcare professionals to monitor wheelchair athletes and introduce specific preventive exercises during the warm-up before the training session, to prevent upper limb injuries.

Author Contributions: Conceptualization: A.D., A.d.S. and A.A.; methodology: A.D. and A.d.S.; formal analysis: A.D., A.d.S. and N.M.; investigation; A.D., N.M., A.P. (Arrigo Palumbo), L.M. and A.P. (Annalisa Petraroli); data curation: A.D., A.d.S. and A.A.; writing—original draft preparation: A.D.

and A.d.S.; writing—review and editing: T.P. and A.A.; visualization, N.M., A.P. (Arrigo Palumbo), G.F., V.G., R.P., L.M., A.P. (Annalisa Petraroli) and T.I.; supervision: A.d.S. and A.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of the University of Catanzaro "Magna Graecia", Catanzaro, Italy.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The dataset is available on request.

Acknowledgments: We would like to thank Lorenzo Isabello for his support in this study.

Conflicts of Interest: The authors declare no conflict of interest.

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