ASSOCIATION BETWEEN CORE MUSCLES AND THE 400-METER OVERGROUND SPRINTING VELOCITY AMONG WHEELCHAIR RACERS

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Abstract

Objective: The study aimed to measure the activity of the core muscles and middle trapezius in T54 class wheelchair racers during full effort over ground sprinting and to determine its association with propulsion velocity.

Methods: Eight male international wheelchair racers, having normal upper limb and partial to normal trunk function (T54 class athletes), propelled their racing wheelchairs on a 400-m competition track with maximal effort. Electromyography (EMG) of the rectus abdominis (RA), iliocostalis lumborum (IL), longissimus thoracis (LT) and middle trapezius (MT) were recorded at each 100 m reach using a wireless surface EMG recorder. Percentage of maximal voluntary contraction (%MVC) was measured and correlated with propulsion velocity.

Results: Median %MVC of RA, IL, LT and MT were 54.2, 43.9, 30.6 and 35.6%, respectively. A positive association to propulsion velocity was found in RA ($p = 0.04$, r = 0.73) while a negative association to propulsion velocity was also found in MT ($p = 0.03$, r = -0.77).

Conclusion: Abdominal function was activated most and associated with propulsion velocity among male T54 class wheelchair racers. In addition, optimizing scapular retraction may benefit propulsion velocity.

Keywords : Athlete athletics, Disabilities, Paraplegia, Sports, Propulsion

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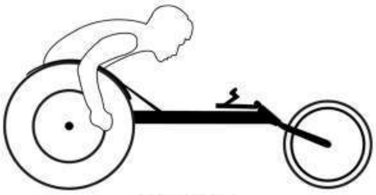
Introduction

Wheelchair racing is an international sports competition for people with physical challenges. In spite of its popularity among athletes and spectators, the complexity of wheelchair racing propulsion is still not totally understood; and thus, no ideal racing stroke pattern has been commonly accepted. (1) Unlike able-bodied athletes, wheelchair racers comprise athletes with spinal cord injury, poliomyelitis, cerebral palsy and limb dysfunction. This wide range of physical impairments in terms of muscle weakness, spasticity, joint contracture and spinal deformity leads to vast variations of propulsion styles among athletes. Therefore, for coaches and sport professionals to design an effective training program for wheelchair racers remains challenging.

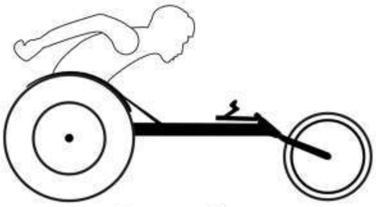
Most articles regarding the wheelchair racing sport regard propulsion technique as the key to racing performance. (2) This idea might be supported by results from related investigations. Researchers found in a longitudinal study that after six months of training, a group of wheelchair racers propelled faster without any significant change in muscular power and anaerobic capacity.(3) Related investigations revealed that, to propel faster, wheelchair racers needed fast and precise hand contact and to lean the trunk forward.(2, 4-7) In spite of extensive studies, the perfect wheelchair racing stroke has not been completely achieved yet. Most articles have focused on kinesiology and upper extremities work rather than the function of the trunk and scapular musculature which, physiologically, should be another substantial part of propulsion mechanisms. The significance of the core muscles is an issue of interest in sports science.(10-12) Apart from its function as a dynamic stabilizer protecting the spine from injury, some literature regards the core musculature as the power house of the body.(13-15) Although less research has demonstrated the benefits of core training for elite athletes; (16) its relationship to exercise performance has been reported among some athletes such as runners and handball and soccer players. (17-19) It has been shown that healthy subjects propelled regular wheelchairs with energy transferred from the trunk.(20) For wheelchair racing propulsion, increased trunk flexion angle at the initial contact was observed as speed increased.(7) However, core muscles activation during the racing propulsion has never been investigated. Therefore, the significance of the core muscles in racing seems to be a general opinion rather than an established scientific conclusion. Physiologically, the effective energy from the core muscles possibly maximizes the body's kinetic chains; thereby, promoting effective movements of the upper and lower limbs.(14, 15) In fact, rhythmic trunk movement can always be visualized both in racing competition and the laboratory.(1) Hence, the core muscles are certainly activated. The question remains whether the core muscles function contributes to propulsion velocity or is just to maintain the trunk at optimal posture.

The scapular stabilizers are regarded as substantial musculature for upper extremity sports. They provide a stable base for efficient glenohumeral motion through which energy from the trunk can be transferred to the upper extremities.(21-23) However, this musculature seems to have received less attention from most researchers concerning wheelchair biomechanics. One propulsion cycle comprises push and recovery phases determined by hand contact and release from the wheel, respectively (**Figure1**). It was shown that the middle trapezius (MT); one of the scapular stabilizers; begins its contraction in the push phase then continues working through the recovery phase of regular wheelchair propulsion.(24) Thus, the MT probably functions as a link between the trunk and the upper extremity particularly during vigorous activity such as high speed racing wheelchair propulsion. The question is whether or not the MT contributes to racing wheelchair propulsion velocity. More understanding of the core muscles and MT function would provide additional scientific clues for sports professionals to design a training program that genuinely maximizes the athletes' performance. The authors hypothesize that the magnitude of the function of the abdominal, paraspinal and MT muscles would be associated with racing wheelchair propulsion velocity. The aim of the study was to measure activities of the core muscles and MT in T54 class wheelchair racers during racing wheelchair propulsion and to determine its association with propulsion velocity.

Figure 1. Graphics showing racing wheelchair propulsion pattern push and recovery phases are determined by hand contact and release from the wheel, respectively. Among T54 class wheelchair racers, the trunk always moves in the sagittal plane. Magnitude of trunk movement varies among individuals.



Push phase



Recovery phase

Methods

This observational study was conducted to determine the association between racing wheelchair propulsion velocity and the relative magnitude of the core muscles and MT activities. Trunk flexor and extensors were selected because the trunk moves mainly in the sagittal plane during racing wheelchair propulsion.(1, 6) The MT as the scapular stabilizer activated in both push and recovery phases, might be part of the mechanism associated with propulsion velocity. To create an environment similar to wheelchair racing competition, we conducted the study on a standard racing track using the same start and finish line as used in real competition. Recording relative muscle activity and propulsion velocity every 100 m reach allowed performance, while accelerating and maintaining at high speed, to be observed. In response to the hypotheses, the authors correlated propulsion velocity with the relative magnitude of muscle activity at each 100 m reach to find possible associations between propulsion speed and relative muscle function.

Subjects

The ethics of the present study was approved by the Institutional Review Board, Royal Thai Army Medical Department and all ethics guidelines were followed by the authors. Subjects were informed of the benefits and risks of the investigation before signing an institutionally approved informed consent document to participate in the study. Subjects comprised eight male international wheelchair racers of class T54 on the Thai national team. According to the International Paralympic Committee (IPC) athletics classification rules, T54 wheelchair racers refer to athletes who have normal upper limb function with a range of trunk function extending from partial to normal.(25) Classification was confirmed earlier by IPC classifiers. Subjects were excluded from the study if they were injured to the extent that would interfere with their performance. All subjects received a diagnosis of poliomyelitis. Average age was 29±4.81 years and all subjects received the same training and nutrition program. A minimum of eight hours sleep including adequate hydration was ensured before measurement. Subjects' characteristics are shown in **Table 1**.

Table 1. Demographic data and overall propulsion performance of each subject

subject	age	Body weight (kg)	abdominal muscle	paraspinal muscle	propulsion velocity in 400 m (m/sec)
# 1	25	58.9	normal	normal	8.23
# 2	23	41.4	normal	normal	8.05
# 3	28	39.4	normal	partial*	8.00
# 4	36	58.7	normal	normal	7.96
# 5	32	51.7	partial*	partial*	7.74
# 6	24	42.4	normal	normal	7.68
# 7	30	44.6	normal	normal	7.46
# 8	34	54.0	normal	normal	7.24

*Partial = presence of partially atrophic muscle

Training Program

The training program comprised overground propulsion training and weight training. Overground propulsion training was practiced six days weekly in the morning and evening. The program started with 30 to 60 minutes of slow speed propulsion as a warm-up followed by 30 to 60 minutes of alternate high and low speed propulsion. Short distance sprinting and starting propulsion training were added occasionally. Daily training ended with 30 minutes of very slow speed propulsion to cool down. Approximately 20 km distance endurance propulsion was supplemented once weekly. The weight training program comprised two sessions each week of approximately 60 minutes training using resistance between 10 to 15 repetitions maximum. The program aimed to strengthen the shoulder girdle and upper extremity musculature. In addition, supine abdominal curls and prone trunk extension exercise were practiced approximately 20 minutes to maintain trunk muscle strength.

Instrumentation

To measure relative muscle activity, the authors used a portable surface electromyography (MegaWin® ME3000P, Kuopeo, Finland). The skin at the recording site was shaved and cleaned with an alcohol wipe before measurement. Pairs of pre-gelled silver-silver chloride surface electrodes (Red Dot 2258-3, 3M, Ontario, CA, USA) were placed on the muscles of interest unilaterally with a center-to-center distance of 2 cm. Electromyography (EMG) data was sampled at a rate of 1 kHz with 12-bit analog to digital conversion and bandpass filtered at 8 to 500 Hz. EMG signals were recorded in a memory card within a portable machine (compact flash memory, 4Mb) before transferring to a computer to analyze using MegaWin Software, Version 3.2. The magnitude of muscle activity during propulsion was compared with maximal isometric voluntary contraction (MVC) and presented as a percentage of maximal voluntary contraction (% MVC).

Procedures

The study was conducted on a standard 400 m competition track during the afternoon on three consecutive days. Subjects spent approximately 15 minutes of warm-up comprising upper extremity stretching and slow propulsion on the track. Initially, measurement of MVC was performed on a bench. Subjects were asked to perform three trials of maximal isometric contractions against manual resistance. EMG signals from the middle 2 seconds of a 6-second contraction were recorded and then averaged over three trials. For the longissimus thoracis (LT) muscle, the electrodes were placed at a two-finger width lateral from the spinous process of L1. Subjects lifted the trunk from a prone position against manual resistance. For the iliocostalis lumborum (IL) muscle, the electrodes were placed at one-finger width medial from the line between the posterior superior iliac spine and the lowest point of the lower rib at the level of L2. The subject lifted the trunk from a prone position against manual resistance. For the rectus abdominis (RA) muscle, electrodes were placed 3 cm apart and parallel to the muscle fibers so that they were located approximately 2 cm lateral and across from the umbilicus over the muscle belly. From the supine posture with hips and knees stabilized in the flex position, subjects performed a curl-up against manual resistance. For the MT muscle, the electrodes were placed at the midpoint between the medial border of the scapula and the spine at the level of T3. In the prone position, subjects abducted their shoulders horizontally before performing scapular retraction against manual resistance.(26-27) Immediately after MVC measurements, subjects spent approximately 5 minutes propelling on the racing track to be familiar with the wires and electrodes attached to the trunk. To measure muscle activity during propulsion on the racing track, subjects were asked to perform full-effort overground propulsion on the standard 400 m racing track using their own wheelchairs. EMG signals from each muscle were recorded using a portable recorder securely attached to the rear frame of the racing wheelchair. The 400 m propulsion time was measured using a manual stopwatch. One lap distance was equally divided in four 100 m reaches represented by D-1 to D-4. All subjects propelled in lane 3 starting by the curved track and finished by the straight track (**Figure 2**).

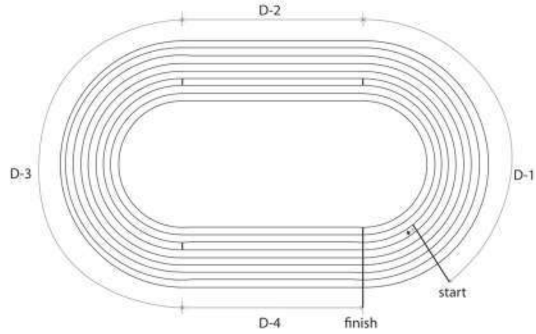


Fig 2. Graphics demonstrating experimental set-up

D-1 = distance from 0 to100 m, D-2 = distance from 100 to 200 m

D-3 = distance from 200 to 300 m, D-4 = distance from 300 to 400 m

Propulsion time in each 100 m reach was recorded using a satellite-connecting stopwatch (Garmin Forerunner® 305, Olathe, KS, USA) attached to the racing wheelchairs. The satellite-connecting stopwatch recorded the time spent within each 100 m distance. After finishing, EMG data were transferred to computer to analyze. EMG data from each 100 m reach was averaged and presented as % MVC. Propulsion velocity in each 100 m reach was correlated with the % MVC of that reach.

Statistical Analysis

For descriptive statistics, data were presented in number and percentage. Continuous data with normal distribution was presented as mean and standard deviation. The % MVC was presented as a median value (min-max). For analytical statistics, the Friedman test was used to compare the % MVC of each muscle in each 100 m distance. Association between the % MVC of each muscle and the velocity was analyzed by Spearman's rank correlation. The alpha level of significance was set at a p value of <0.05. All statistical analyses were performed using STATA/MP, Version12.

Results

Subjects performed 400 m racing wheelchair propulsion with mean propulsion time of 51.47±2.25 s. Mean propulsion time was longest in the D-1 (17.75±1.49 s) then became relatively constant during the D-2 to D-4 (11.38±0.52, 11.50±2.62 and 11.25±1.04 s, respectively). Notably, each subject had individual patterns of relative muscle activation (**Figure 3**).Throughout 400 m propulsion, median %MVC in the RA muscle was the highest, followed by the IL, MT then LT. However, no significant difference of %MVC was found among these four muscles (**Figure 4**).

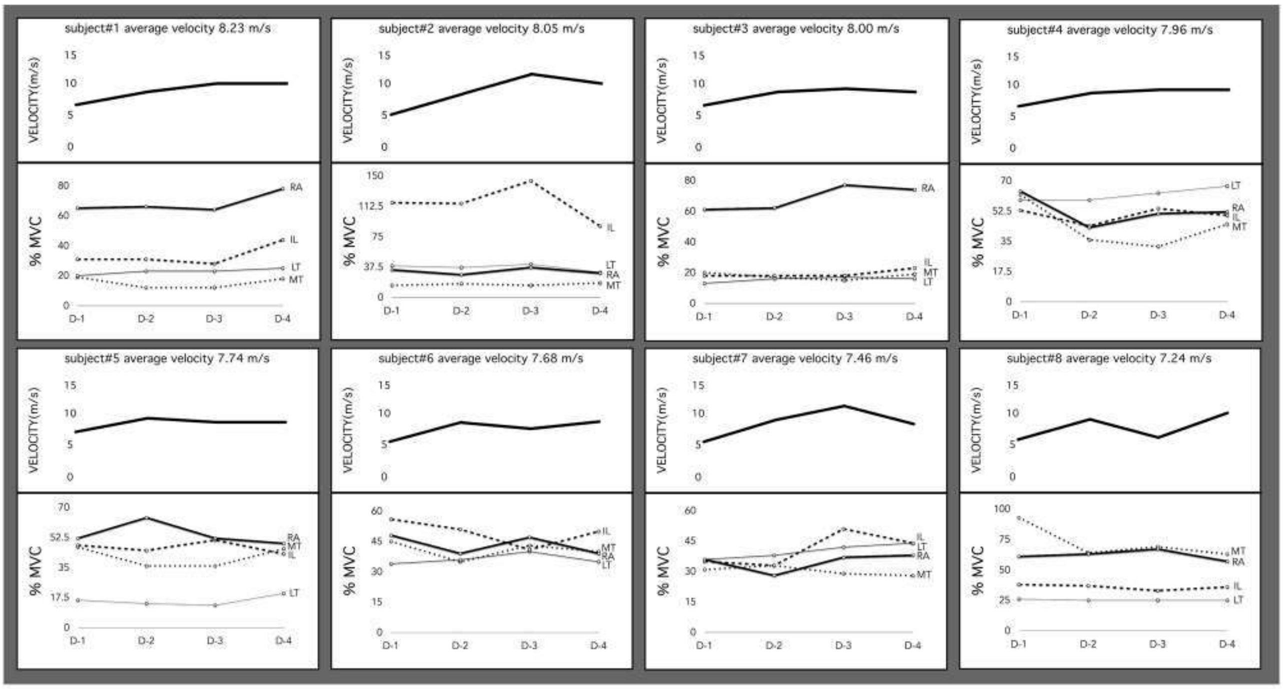


Fig 3. Muscle activation and propulsion speed of each subject

RA = rectus abdominis, IL = iliocostalis lumborum, LT = longissimus thoracis, MT = middle trapezius

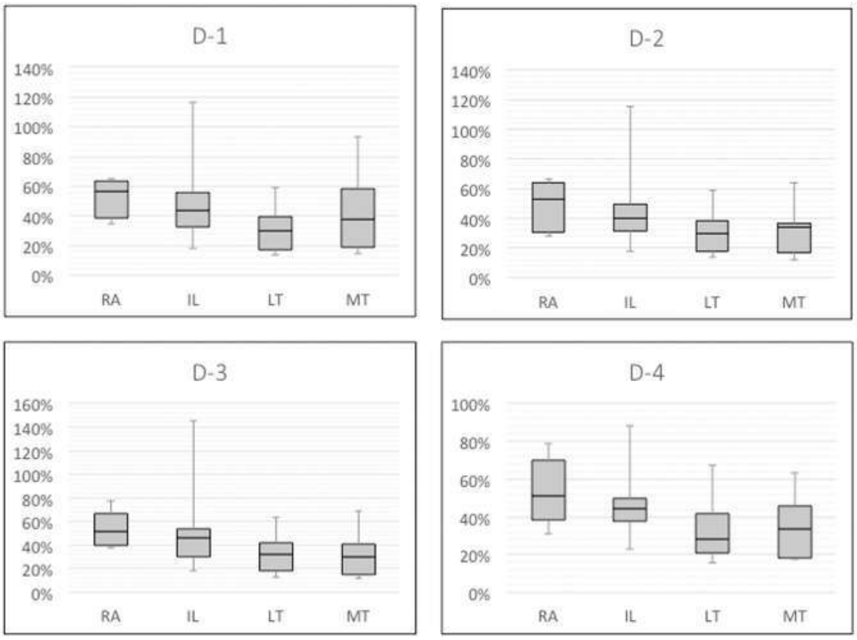


Fig 4. Median % MVC of each muscle

RA = rectus abdominis, IL = iliocostalis lumborum, LT = longissimus thoracis, MT = middle trapezius

When propulsion velocities were correlated with % MVC in each reach, the authors found a significant positive association between % MVC of the RA muscle and propulsion velocity in the D-1 reach (*p* = 0.04, r = 0.73). No significant association was found between %MVC of the RA and propulsion velocity in the D-2, D-3 and D-4 reach. Also, a negative association was observed between %MVC of the MT muscle and propulsion velocity in the D-3 reach (*p* = 0.03, r = -0.77). Moreover, no significant association was observed between %MVC of the MT and propulsion velocity in the D-1, D-2 and D-4 reach, and no significant association between propulsion velocity and % MVC was found in the IL and LT muscles throughout the 400 m propulsion.

Discussion

Faster athletes had a tendency to use more abdominal muscle than slower ones. The results not only provided initial scientific evidence indicating the significance of the abdominal muscle to racing wheelchair propulsion but also explained the previous observation that trunk flexion at the initial hand contact increased as speed increased.(7) It might be the energy transferred from the contracting abdominal muscle that promotes powerful upper extremity push.(20) Interestingly, a significant association occurred only in the first 100 m but not in the remaining 300 m. This might indicate that abdominal function is substantial for starting acceleration propulsion but contributing less to performance in the relatively constant speed phase. Other factors might contribute to success in this phase. Level of association by 0.73 between abdominal function and propulsion velocity indicated that only one half of the subjects propelled under this association in the present study. Based on these results, abdominal function of T54 wheelchair racers may need to be promoted particularly for athletes intending to improve starting acceleration performance.

The relative magnitude of the back muscles such as the IL and LT activities were not associated with racing wheelchair propulsion velocity in the present study. Therefore, strong exertion of the back muscles may not benefit wheelchair racing speed. The result was irrelevant to part of our hypotheses. A study of starting propulsion analysis in a wheelchair racer revealed that the trunk extended away from the pushing hands after reaching its peak flexion, occurring approximately at the point of hand contact.(1) To the authors' best knowledge, the role of the back muscles in racing propulsion has never been investigated. However, based on our results, the authors propose that the main function of the back muscles is to provide a relatively stable base for the push rather than giving out energy to the extremities. The lack of association with propulsion speed for the back muscles seems to be related to motion in racing propulsion, performed mainly by pushing rather than pulling (**Figure1**). Although the relative magnitude of the back muscle function was not associated with 400 m wheelchair racing speed, the back muscles were contracting throughout the 400 m distance. Therefore, this may provide a clue that the back muscles may need more endurance than strength or coordination training. Notably, during the first 100 m of acceleration, propulsion velocity was associated only with the abdominal not with the back muscles function. This might indicate that abdominal function is more important than back muscle function in T54 class wheelchair racers competing in the 400 m race.

The authors hypothesized that faster wheelchair racers would exert the MT at a greater magnitude. Unexpectedly, the results showed that the slower subjects had a tendency to use more MT, contrary to the hypothesis. This may indicate that strong exertion of the MT is not only unnecessary but also related to the mechanisms that hinder propulsion speed. Notably, a significant association occurred only in the third 100 m curve track. The authors assumed that some differences may exist in mechanisms between high speed propulsion on the straight and curve tracks. As a result, the authors propose that the main function of the MT in wheelchair sprinting is to navigate scapular motion rather than give out energy to propel. Slower subjects not only tended to use more MT but also showed less speed consistency after 200 m (**Figure 3**). This speed variability may be due to fatigue. Based on our results, overly strong scapular retraction does not seem to produce a decent stroke pattern among T54 class wheelchair racers. Future research should focus more on the role of scapular motion during racing wheelchair propulsion.

Full effort overground racing propulsion on a standard racing track has created more realistic conditions than those in the laboratory setting.(2, 4) In addition, only four sets of electrodes attached to the trunk should have allowed subjects to propel naturally so that the muscle activation and coordination were greatly similar to that of real competition. However, a study conducted outside the laboratory might be influenced by uncontrolled environmental factors especially wind. Propulsion times recorded from each subject that were close to his personal best reflected that subjects propelled wheelchairs with nearly maximal exertion. Based on IPC classification, T54 athletes can be individuals with poliomyelitis, spinal cord injury and lower limb amputation or dysfunction. These physical differences may influence propulsion style or performance. While athletes with poliomyelitis generally have lower body weight due to massive muscle wasting, heavier amputated wheelchair racers may propel with isometric contraction of the remaining lower limb muscles and spinal cord injured athletes may be challenged by muscle spasticity. Unfortunately, only subjects with poliomyelitis were enrolled in the present study. In fact, classifications for wheelchair racers are determined by disabilities not by diseases. Currently, the IPC considers all lower limb variations as comparable disabilities for T54 wheelchair racers.(29) According to the definition of T54 class wheelchair racers, intra-class variations of the trunk function extend from partial to normal. Whether intraclass variations significantly influence muscle activation remains unknown. The characteristics of our subjects were fairly homogeneous in terms of their physical disabilities as well as training protocols provided. However, variations of the trunk muscle exertion were still observed. We believe that this was not due to physical differences among subjects. This might be attributed to the lack of knowledge of how to properly exert trunk muscles. Based on the characteristics of subjects in the present study, our results were established from athletes with full to nearly full trunk function. Therefore, findings from the present study may not represent individuals with poor trunk function. The study design provided only initial scientific evidence showing the significance of the relative core muscles and MT function in wheelchair racing velocity. Therefore, the present study is not considered as strong evidence demonstrating the effects of core activation styles because an association cannot determine the cause or effect of an event. Further prospective randomized placebo-controlled trials are still required to demonstrate the effects of core activation style or training protocols concerning wheelchair racing performance. However, the authors believe that the results from the present study have provided initial knowledge for practitioners and investigators in this area.

The small sample size may have reduced the power of statistical significance and caused the results to be less generalized. Findings from the present study should be applied with caution to athletes of other conditions such as female athletes, individuals with poor trunk function or impaired upper limb function. Results from the present study provided initial evidence that the magnitude of abdominal function was associated with propulsion velocity at the first 100 m among male T54 class wheelchair racers with poliomyelitis. Therefore, abdominal function while propelling should be promoted whereas optimizing scapular retraction may benefit propulsion velocity. The authors recommend that, apart from overground practice, a wheelchair roller or treadmill with biofeedback could be used to cultivate the proper trunk and MT muscle function.

Conclusion

Abdominal function was activated most and associated with propulsion velocity among male T54 class wheelchair racers. In addition, optimizing scapular retraction may benefit propulsion velocity.

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References

1. Moss AD, Fowler NE, Goosey-Tolfrey VL. The intra-push velocity profile of the over-ground racing wheelchair sprint start. J Biomech 2005; 38: 15-22.
2. Vanlandewijck Y, Theisen D, Daly D. Wheelchair propulsion biomechanics: implications for wheelchair sports. Sports Med 2001; 31: 339-67.
3. Kumerddee W, Tongsiri N. Corelation between anaerobic fitness and starting velocity in Thai national team wheelchair racers. J Thai Rehabil Med 2010: 20: 68-72.
4. Chow JW, Levy CE. Wheelchair propulsion biomechanics and wheelers' quality of life: an exploratory review. Disabil Rehabil Assist Technol 2011; 6: 365-77.
5. van der Woude LH, Bakker WH, Elkhuizen JW, Veeger HEJ, Gwinn T. Propulsion technique and anaerobic work capacity in elite wheelchair athletes: cross-sectional analysis. Am J Phys Med Rehabil 1998; 77: 222-34.
6. Wang YT, Deutsch H, Morse M, Hedrick B, Millikan T. Three-dimensional kinematics of wheelchair propulsion across racing speeds. Adapt Phys Act Q 1995; 12: 78-89.
7. Limrungreungrat W. and Wang YT. Three-dimensional pushrim force during different racing wheelchair propulsion speeds. In: Routledge handbook of ergonomics in sport and exercise. 1st Edition. New York: Roudledge, 2014. pp. 549-56.
8. Chow JW, Millikan TA, Carlton LG, Morse MI, Chae WS. Biomechanical comparison of two racing wheelchair propulsion techniques. Med Sci Sports Exerc 2001; 33: 476-84.
9. Guo LY, Su FC, An KN. Effect of handrim diameter on manual wheelchair propulsion: mechanical energy and power flow analysis. Clin Biomech 2006; 21: 107-15.
10. Willardson JM. Core stability training: applications to sports conditioning programs. J Strength Cond Res 2007; 21: 979-85.
11. Mautner KR, Huggins MJ. The young adult spine in sports. Clin Sports Med 2012; 31: 453-72.
12. Shinkle J, Nesser TW, Demchak TJ, McMannus DM. Effect of core strength on the measure of power in the extremities. J Strength Cond Res 2012; 26: 373-80.
13. Hill J, Leiszler M. Review and role of plyometrics and core rehabilitation in competitive sport. Curr Sports Med Rep 2011; 10: 345-51.
14. Bliss LS, Teeple P. Core stability: the centerpiece of any training program. Curr sports med rep 2005; 4: 179-83.
15. Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. Sports Med 2006; 36: 189-98.
16. Hibbs AE, Thompson KG, French D, Wrigley A, Spears I. Optimizing performance by improving core stability and core strength. Sports Med 2008; 38: 995-1008.
17. Sato K, Mokha M. Does core strength training influence running kinetics, lower-extremity stability, and 5000-M performance in runners? J Strength Cond Res 2009; 23: 133-40.
18. Saeterbakken AH, van den Tillaar R, Seiler S. Effect of core stability training on throwing velocity in female handball players. J Strength Cond Res 2011; 25: 712-18.
19. Borghuis AJ, Lemmink KA, Hof AL. Core muscle response times and postural reactions in soccer players

and nonplayers. Med Sci Sports Exerc 2011; 43: 108-14.

20. Guo LY, Su FC, Wu HW, An KN. Mechanical energy and power flow of the upper extremity in manual wheelchair propulsion. Clin Biomech 2003; 18: 106-14.
21. Kibler B. Biomechanical analysis of the shoulder during tennis activities. In: Clinics in sports medicine, racquet sports. Richard C. Lehman, eds. Philadelphia: W.B. Saunders Company, 1995. pp. 79-85.
22. Kaczmarek P, Lubiatowski P, Cisowski P, Grygorowicz M, Epski M, Dugosz J, et. al. Shoulder problems in overhead sports. Part I - biomechanics of throwing. Pol Orthop Traumatol 2014; 15: 50-8.
23. Paine R, Voight ML. The role of the scapula. Int J Sports Phys Ther 2013; 8: 617-29.
24. Mulroy SJ, Gronley JK, Newsam CJ, Perry J. Electromyographic activity of shoulder muscles during wheelchair propulsion by paraplegic persons. Arch Phys Med Rehabil 1996; 77: 187-93.
25. International Paralympic Committee. IPC Athletics Classification. Handbook of IPC athletics classification workshop, 2006. pp. 10-11.
26. Konrad P. Signal processing-amplitude normalization, The ABC of EMG-A practical introduction to kinesiological electromyography. Scottsdale: Noraxon U.S.A., 2006. pp. 15.
27. Criswell E. Electrode placements. In: Cram's introduction to surface electromyography. 2nd Edition. Sudbury, Massachusetts: Jones and Barlett Publishers, 2011. pp. 257-384.
28. Rankin JW, Richter WM, Neptune RR. Individual muscle contributions to push and recovery subtasks during wheelchair propulsion. J Biomech 2011; 44: 1246-52.
29. Tweedy S. Research report, IPC athletics classification project for physical impairments: final report – stage 1. University of Queensland, 2009. pp. 37.