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Sport in people with tetraplegia: Review of recent literature

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Sport participation in people with spinal cord injury (SCI) has been studied extensively, however there is little evidence available on sports for people with cervical SCI (tetraplegia). Due to physical consequences of cervical SCI people with tetraplegia have very limited possibility to engage in vigorous physical activity but increasing number of adaptive sports for people with tetraplegia allowed scientist to explore more intensively diverse aspects of sport participation in this population. The purpose of this review was to summarize the findings of recent studies related to sport in people with tetraplegia published in years: 2002-2013. A comprehensive search of computer databases was performed to identify relevant studies. These studies were grouped according to their subjects into five main areas of research involving athletes with tetraplegia: 1) muscle strength and kinematics, 2) cardiovascular performance and functions, 3) thermoregulation system, 4) respiratory functions, and 5) social aspects of sport. Most of recent research into sport in people with tetraplegia is related to physiological body response to intensive physical training. Researchers do agree that adequately provided sport training in people with tetraplegia improves several physiological parameters such as peak power output or peak oxygen uptake. As biomedical aspects of sport in people with tetraplegia are already well documented in the literature it is suggested that future research should focus more on psychosocial aspect of this activity.

KEY WORDS: tetraplegia, quadriplegia, sport, wheelchair rugby, twin basketball, muscle strength and kinematics, cardiovascular performance and functions, thermoregulation system, respiratory functions, social aspects of sport.

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What is already known on this topic?
Participation in sport following spinal cord injury (SCI) brings many positive biomedical and psychosocial effects. Up-to-date knowledge in these areas is based mainly on people with paraplegia i.e. SCI in thoracic, lumbar or sacral section of the spinal cord. Information on people with tetraplegia (cervical SCI) participating in sport is very limited.

Introduction

Sport participation of people with spinal cord injury (SCI) has been studied extensively. Physiological and psychological benefits of involvement in sport following SCI has been shown mainly on the basis of individuals with paraplegia [1]. Unfortunately, much less evidence is available on sports for people with cervical SCI. Such injury results in tetraplegia – the loss of hand and upper limb function with impairment or loss of motor and/or sensory function. In addition to a loss of sensation, muscle functioning and movement, individuals with cervical SCI also experience many other changes which may affect bowel and bladder, presence of pain, sexual functioning, gastrointestinal function, swallowing ability, blood pressure, temperature regulation and breathing ability. Numerous secondary complications may arise from cervical SCI including deep vein thrombosis, heterotopic ossification, pressure ulcers and spasticity [2].

Persons with tetraplegia despite their disability may practice several different sports such as swimming, table tennis, archery or boccia [3]. However, due to physical consequences of cervical SCI they have very limited possibility to engage in vigorous physical activity. One of such opportunities is a wheelchair rugby – team sport designed especially for people with tetraplegia. Wheelchair rugby combines elements of ice hockey, basketball, and football to create a sport that is aggressive, strategic, fast-moving, and hard-hitting [4]. People with cervical SCI can also play other team sport called twin basketball [5]. Twin basketball is relatively new sport developed in Japan which includes players with tetraplegia. It is a variation of wheelchair basketball with two basketball nets on either end of the playing court, one at regulation height and the other approximately four feet high. Players with tetraplegia shoot on the lower basket [6]. Apart from the above mentioned team sport, people with cervical SCI may practice individual sports such as hand-biking [7]. Increasing number of adaptive sports for people with tetraplegia allowed scientist to explore more intensively diverse aspects of sport participation in this population. The last critical review of publications related to physical capacity in wheelchair-dependent persons with SCI was published in 2006, however authors analyzed both tetraplegics and paraplegics groups [8]. The authors of the review found that physical capacity in persons with SCI is reduced mainly as a result of diverse population and methodological differences. In conclusion they suggested that standardized measurement of physical capacity in persons with SCI is needed in order to compare results of different studies [8].

The purpose of this review was to summarize the findings of recent studies into sport only in people with tetraplegia. This review was seeking answers to the following questions:

1. What are the latest directions of research in relation to sport in people with tetraplegia?
2. What results seem to be the most important for the development of science in this area?
3. In what matters covered by these research scientists are in agreement, and in which they represent different opinions and conclusions?
4. What are the most common limitations and weaknesses with regard to research related to athletes with tetraplegia?
5. What are the future directions of research in relation to sport in people with tetraplegia?

Methods

A comprehensive search of computer databases (Academic Search Complete, SPORTdiscus, MEDLINE, Health Source, MasterFILE Premier) was performed to identify relevant studies of sport in people with tetraplegia cross-indexing the keywords: 'tetraplegia'/'quadriplegia' with 'sport' and 'wheelchair rugby'/'quad rugby'/'rugby'. The following inclusion criteria were used: (a) only research articles were reviewed; (b) full text of the article was available; (c) articles were published in peer-reviewed journals; (d) in English language; (e) within last 10 years i.e. from January 2002 until January 2013. Articles were excluded from the analysis if they were designed as case report based on one person only, or to examine tetraplegia/quadriplegia as a result of sport injury. Finally 15 studies meeting the inclusion criteria were identified (Fig. 1).

These studies were grouped according to their subjects into five main areas of research involving athletes with tetraplegia: muscle strength and kinematics, cardiovascular performance and functions, thermoregulation system, respiratory functions, and social aspects of sport (Table 1).

Muscle strength and kinematics

Tetraplegia results in impairment of function in the arms, as well as in the trunk, legs and pelvic organs. The loss of upper limb function, especially the use of the hands is one of the most significant and devastating losses an individual can experience. The strength of all working muscles of upper body is extremely significant in completing basic activities of daily living such as self-feeding, dressing, bathing and toileting. Mobility needs such as transfers from surface to surface (e.g. from wheelchair to bed), transitional movements such as rolling, changing position from lying down to sitting, and wheelchair mobility are also completed by people with tetraplegia using the upper extremities [20].

Tabęcki et al. [9] undertook study assessing the effects of 15 months strength training on the physical capacities in 4 Paralympic athletes with cervical SCI (1 swimmer and 3 wheelchair rugby players). The isokinetic dynamometer and arm crank ergometer were used for measurements. Study participants could take part in strength training only by using weights fixed to their hands due to the limited function of arm flexors, and greatly reduced hand gripping function. The modified strength training equipment for athletes with tetraplegia allowed maximal loading of their shoulder girdle. As a result of this approach strength training improved the maximal force of arms in athletes with tetraplegia and positively affected their physical endurance. Unfortunately, these results were not confirmed in people

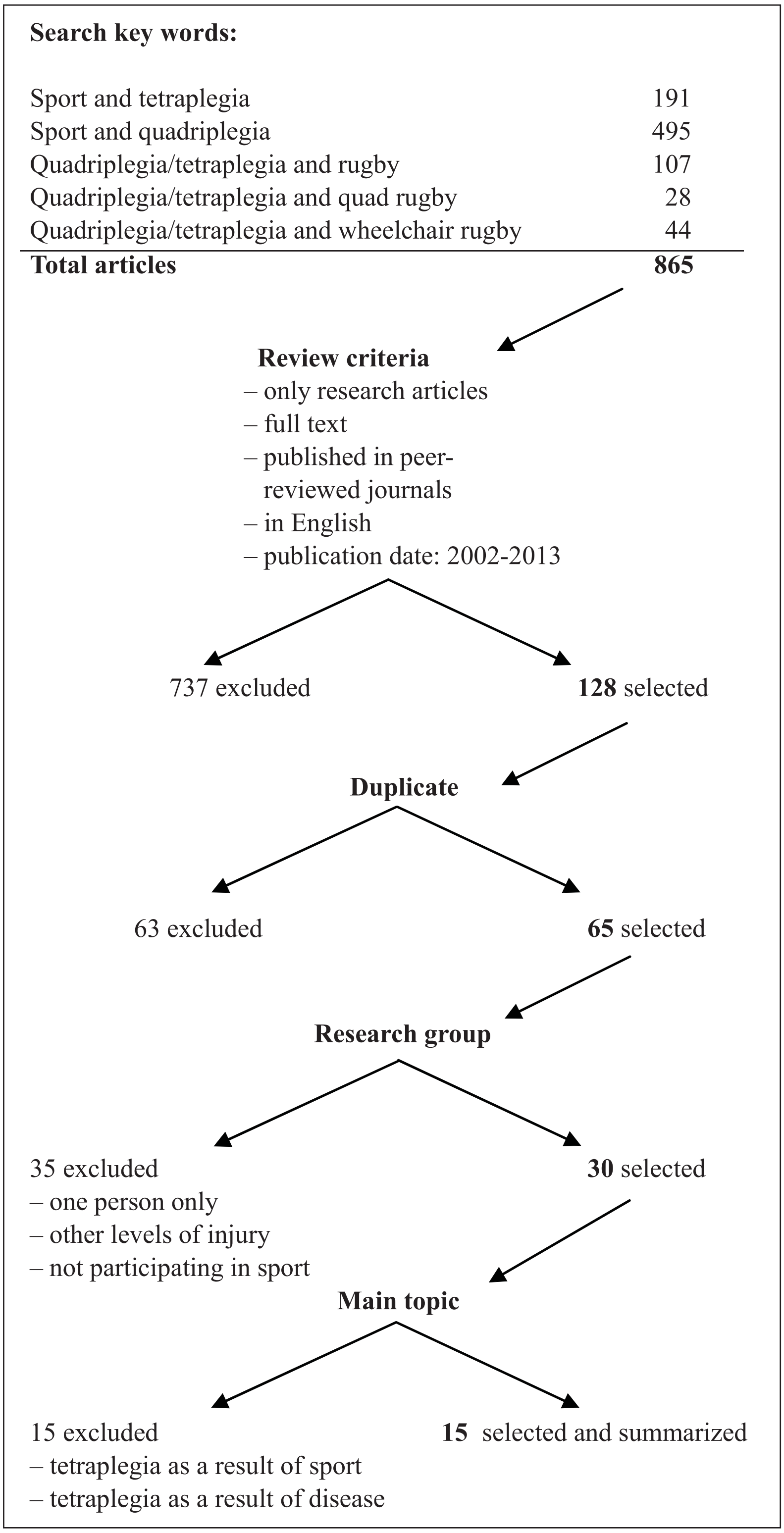

Figure 1. Flowchart for search and selection of studies

with tetraplegia practicing individual sport such as hand-cycling. In the Valent et al. [7] study no clinically relevant improvements in muscle strength were found in 22 people with cervical SCI after 19 sessions of hand-cycle training.

In turn Nunome et al. [10] investigated shooting ability in the group of twin basketball players with tetraplegia by specifying vectors in the joints of upper limb and 3-D video analysis. The participants performed ten throws by one hand in the stabilized seated position in the wheelchair. The comparison of 6 wheelchair basketball players and 6 able-bodied players showed significantly larger displacements of right shoulder and reduced ball release velocity for the tetraplegic group. The authors concluded that it could be due to an insufficient musculature of the wrist compensating those available around the elbow and shoulder. However, without additional kinetic analysis the results of this study are still insufficient to determine the role of specific muscles related to shooting motion in people with tetraplegia.

Cardiovascular performance and functions

People with tetraplegia have a decreased ability to control the cardiovascular system due to the disturbed vascular innervation and neurohumoral changes [21]. This can lead to orthostatic hypotension i.e. fall in systolic blood pressure of 30 mmHg or more when changing from supine to standing position caused by autonomic nerve dysfunction [22]. People with cervical SCI also show a smaller diameter and lower compliance of the common femoral artery supplying the lower extremities than the able-bodied, indicating a partially disused response of the common femoral artery [23].

Otsuka et al. [5, 6] published two studies related to cardiovascular performance in athletes with tetraplegia playing twin basketball. Both articles were based on the same participants i.e. 10 athletes with tetraplegia, 10 untrained people with tetraplegia, and 10 able-bodied people

Table 1. Research articles related to sport in people with tetraplegia published in years 2002-2013

Author/s	Tetraplegic athletes (n)	Sport discipline	Investigated research area
Tabęcki et al. (9)	4	WR /SW	Muscle strength
Nunome et al. (10)	6	TB	Kinematics
Otsuka et al. (5)	10	TB	Cardiovascular functions
Otsuka et al. (6)	10	TB	Cardiovascular functions
Hübner-Woźniak et al. (11)	14	WR	Cardiovascular performance
Barfield et al. (12)	9	WR	Cardiovascular performance
Abel et al. (13)	13	WR	Cardiovascular performance
Morgulec et al. (14)	19	WR	Cardiovascular performance
Morgulec et al. (15)	14	WR	Cardiovascular performance
Valent et al. (7)	22	HC	Cardiovascular performance
Goosey-Tolfrey et al. (16)	8	WR/WT	Cardiovascular performance
Webborn et al. (17)	8	WR /WT	Thermoregulation system
Webborn et al. (18)	8	WR /WT	Thermoregulation system
Taylor et al. (19)	7	WR	Respiratory functions
Goodwin et al. (4)	11	WR	Social aspects of sport

WR – wheelchair rugby; TB – twin basketball; WT – wheelchair tennis; SW – swimming; HC – hand-cycling

(exactly the same demographic characteristics of study participants, and the same research procedure). The purpose of the first study was to examine the sympathetic nervous system activity during orthostatic challenges in athletes with tetraplegia using power spectral analysis of systolic blood pressure and heart rate variables [5]. Spectrum analysis of the electrocardiography interval and blood-pressure on a beat-by-beat basis during head-up tilt of 60° sitting were performed. The results suggested that training enhances cardiovascular stability in people with tetraplegia. The untrained participants of this study showed autonomic hyper reaction, while athletes with tetraplegia showed an improvement in regulating heart rate and blood pressure variability during an orthostatic challenge. In the second article Otsuka et al. [6] aimed to examine exercise-induced changes of the diameter and compliance of artery in athletes with tetraplegia using a noninvasive ultrasound technique. The athletes with tetraplegia manifested functional adaptation of the brachial artery i.e. upper extremity artery participating in the wheelchair propulsion.

Hübner-Woźniak et al. [11] examined the effect of wheelchair rugby training on the erythrocyte antioxidant enzymes activity and on antioxidants in plasma in able-bodied and wheelchair rugby players with tetraplegia. Four groups of athletes participated in the study: 19 sedentary able-bodied males, 10 sedentary males with tetraplegia, 22 able-bodied rugby players, and 14 wheelchair rugby players with tetraplegia. The results of this study revealed similar adaptive response of cardiovascular system to training in both able-bodied and wheelchair rugby players i.e. improved resistance to oxidative stress.

The purpose of Barfield et al. [12] study was to determine the ability of individuals with a cervical SCI (n = 9) to achieve and sustain a cardiorespiratory training intensity during wheelchair rugby. The tests were performed using the arm ergo-meter with stage increases each minute to determine peak heart rate and power output. Results of this study indicated that wheelchair rugby training enables participants to reach a training intensity associated with improved cardiorespiratory fitness (70% heart rate reserve), and that the type of training activity dictates the extent to which individuals sustain such a threshold. These findings supported the ability of wheelchair rugby training sessions to invoke a consistent, meaningful exercise load. The authors concluded that if wheelchair rugby players can achieve and sustain a cardiorespiratory training intensity during training, then this sport can be recommended as a viable mode for improving cardiorespiratory fitness for people with cervical SCI.

Abel et al. [13] investigated the parameters of functional efficiency (cardiopulmonary and metabolic response) during exercise on two kinds of ergometers (the arm crank and frictionless roller) in 13 wheelchair rugby players with tetraplegia. Comparison of the heart rate and lactate parameters at the arm crank and on the frictionless roller under maximum load revealed significantly higher heart rate with no significant differen-ces in lactate. The results indicated that there was no significant differences between those two methods and both ergomteres can be used for assessment of functional efficiency in athletes with tetraplegia.

The aim of Morgulec et al. [14] study was to compare the components of anaerobic performance in two groups of male individuals with tetraplegia. The first group included 19 athletes from Polish Wheelchair Rugby League, and the second group included 12 individuals with tetraplegia passive in terms of sport. The arm crank ergometer was used for testing. Results showed that there was a significant differences between active and sedentary groups in anaerobic performance parameters. The active males presented higher values of muscle endurance and lower fatigability than sedentary ones. The authors suggested that everyday activity improves independence of people with tetrapelgia.

Morgulec et al. [15] investigated the effect of one year training on aerobic performance in 14 wheelchair rugby players with tetraplegia. For the examination of physiological response to maximal performance the authors used treadmill adapted for wheelchairs. The findings revealed that one year training period had significant impact on increasing the peak oxygen uptake and improved physiological response to maximal efficiency in people with tetraplegia. These results were confirmed by the Valent et al. [6] study. The researchers aimed to evaluate the effects of a structured hand cycle interval training intervention on physical capacity in 22 people with tetraplegia. The primary outcome measures in the study, i.e. peak power output and peak oxygen uptake (tested on a motor-driven treadmill) showed significant improvements over the 19 sessions of hand cycle training. However, no improvements in functional vital capacity or peak expiratory flow were found.

Research of Goosey-Tolfrey et al. [16] aimed to obtain a physiological profile and examine relation between aerobic and sprint capacity in 8 highly trained athletes with tetraplegia (4 wheelchair rugby players and 4 wheelchair tennis players). Exercise testing was performed on a modified cycle ergometer adapted for upper body exercise so that athletes could remain in their everyday wheelchairs for testing. The study identified a significant correlation between peak oxygen uptake and maximal power output in examined athletes with tetraplegia. However, there was high variability of aerobic capacity among the study participants.

Thermoregulation system

The extent of the thermoregulatory impairment relates to the level of SCI. The most susceptible of such complications are people with tetraplegia [24]. SCI causes thermoregulatory impairment with a detrimental effect on performance. Any strategies that delay or reduce the increase in body temperature during exercise may enhance performance in the heat [25]. Lower skin temperatures enable a greater temperature gradient for dissipating heat from deeper regions of the body. Cooler skin temperatures also mean that less of the total cardiac output is directed towards the skin, possibly allowing more blood to be directed to active skeletal muscle. Lower skin and core temperatures can also delay the onset of sweating and decrease sweat rate, resulting in a conservation of body water during a prolonged competitive event thus enhancing performance [26].

Webborn et al. [17, 18] published two studies related to thermoregulatory (cooling strategies) in people with cervical SCI. Both studies involved 8 athletes with tetraplegia (4 wheelchair rugby players and 4 wheelchair tennis players) who performed intermittent arm crank exercise in the heat (32° C; 50% relative humidity). The main objective of the first study was description of the effects of 20 minutes precooling or cooling during intermittent sprint exercise (for 28 minutes) and their impact on attenuation the rise of core temperature [17]. The results showed that both strategies reduced thermal strain and they can have an impact on improving functional capacity of athletes with tetraplegia. The purpose of the second article was to assess whether cooling strategies before and during exercise in the heat enhance sprint performance in athletes with tetralegia performing exercise for a maximum of 60 minutes or until exhaustion [18]. Trials involved a no-cooling control, precooling or cooling during exercise. The results of this study showed that precooling and cooling during exercise strategies can improve the duration of repeated sprinting capacity in athletes with tetraplegia. The authors recommended that athletes with tetraplegia performing intermittent sprint exercise in hot conditions should use precooling or cooling during exercise to improve performance. However, the specific cooling technique should match the power output typical of the sport event.

Respiratory functions

Respiratory dysfunction resulting from cervical SCI depends on the level of injury and the extent of innervation. The higher level lesions result in dennervation of progressively more of the expiratory and inspiratory muscles. Although the primary consequence of SCI is dennervation of the respiratory pump, secondary consequences occur within the lungs because of the inability to effectively distend and inflate the lung to its full capacity. As a consequence, the compliance of the lungs diminishes with increasing time after SCI. Cervical SCI results in a decrease in the capacity of the lungs and chest wall for pressure, expiratory reserve volume, and airflow generation [27].

Taylor et al. [19] undertook study in order to find out whether cervical SCI increases the potential for exercise-induced diaphragmatic fatigue and mechanical ventilator constraint in 7 Paralympic wheelchair rugby players. The tests were performed using the arm-crank exercise to the limit of tolerance at 90% of their predetermined peak work rate. During the exercises researchers observed in athletes with tetraplegia a sudden sustained rise in operating lung volumes and an eightfold increase in the work of breathing. The authors concluded that highly trained athletes with cervical SCI do not exhibit objective evidence of exercise-induced diaphragmatic fatigue, and rarely reach mechanical ventilatory constraint during sustained high-intensity arm-crank exercise. These findings suggest that the respiratory system has sufficient capacity to cope with the demands placed on it during upper body exercise in this population.

Social aspects of sport

Goodwin et al. [4] completed the descriptive study exploring the sense of community from the perspective of 11 wheelchair rugby players with tetraplegia. The sense of community was understood as members' feeling of belonging, a feeling that members matter to one another and to the group, and a shared faith that members' needs will be met through their commitment to be together. Study participants shared their experiences through the phenomenological methods of semistructured focus group interviews and artifacts. Three themes emerged from the thematic analysis: (a) it's okay to be a quad, (b) don't tell us we can't, and (c) the power of wheelchair rugby. The wheelchair rugby players found membership with a community of people with common interests who shared understanding of their disability. As a result they were confident that it is okay to be a quad for themselves and their immediate families. The need to be a wheelchair rugby player and be independent in daily life was in contrast to the message from the medical staff regarding their health, especially risk of shoulder injury. The players felt an emotional connection that was reflected in their shared group experiences. The athletes were learning from each other and found confidence through group affiliation. Wheelchair rugby was rewarding to study participants as their individual and group goals were formulated and fulfilled. The athletes with tetraplegia had sense of community and the membership, fulfillment of need, and shared emotional connections. They expressed themselves through being wheelchair rugby players.

What this study adds?

Increasing number of adaptive sports for people with tetraplegia allowed scientist to explore more intensively diverse aspects of sport participation in this population. This review describes results of recent research outcomes related to sport in people with tetraplegia in five areas: 1) muscle strength and kinematics, 2) cardiovascular performance and functions, 3) thermoregulation system, 4) respiratory functions, and 5) social aspects of sport.

Conclusion

The authors of this review are fully aware that it may not include all important research outcome related to sport in tetraplegia within the last ten years. In such a case it may be due to selection of key words used in different research articles. Initial literature search based on the main key words (tetraplegia, quadriplegia, sport) produced very confusing mixed records from the scientific databases. Some of the articles were totally out of scope of this review. This is why additional key words were used (wheelchair rugby, quad rugby and rugby) in order to track down relevant articles. Finally 15 studies were included in this report but it is possible that there is more interesting research in this area but hidden under other key words or published in other (than English) languages. The review of analyzed articles allowed to draw following conclusions:

1. Most of the recent research into sport in people with tetraplegia is related to physiological body response to intensive physical training. The most often investigated areas were cardiovascular performance and functions as a result of sport training undertaken by people with cervical SCI. Other physical capacities related to participation in sport such as changes in

muscle strength or thermoregulation system also received attention from the research community but they were less frequently studied within the last ten years. It should be emphasized that Polish scientists are very active in this area of research as 4 out of 15 reviewed studies are coming from the research team representing the Józef Piłsudski University of Physical Education in Warsaw.

2. It is difficult to choose only one most important outcome of research studies involving athletes with cervical SCI. The results of new research directions seem to be very important for the development of science in this area. Within the period of this review the following type of studies were undertaken for the first time in this population: (a) evaluation of diaphragmatic fatigue, (b) changes of the diameter and compliance of artery, (c) evaluation of adaptation to oxidative stress. The grooving body of literature supporting positive aspects of vigorous physical activity for people with tetraplegia shows that wheelchair rugby is a great option for those people who would like to improve their health condition. This seems to be the most important practical finding coming from the recent research (11 out of 15 studies were based on wheelchair rugby players).
3. Researchers do agree that adequately provided sport training in people with tetraplegia improves several physiological parameters such as peak power output or peak oxygen uptake. However, occurrence of these positive effects depends on type of sport practiced by people with cervical SCI. From the recent research it is known that e.g. participation in wheelchair rugby brings more positive physiological effects than participation in hand-cycling. No contradictory opinions have been found with regard to studied effects of sports participation involving athletes with tetraplegia. Some studies question the utility of different research protocols used in this population.
4. The most common limitation in this research is seen in relatively small number of study participants (sometimes limited to several people only). On the other hand it is understood that there are not many people with tetraplegia who devote their life to intensive sport training. The other limitation is related to different research protocols used to assess the same variables.
5. As biomedical aspects of intensive sport training in people with tetraplegia are already well documented in the literature it is suggested that future research should focus more on psychosocial aspect of this activity in order to provide balance in knowledge between these two areas of sport participation. Future research should also take into account potential negative effects of vigorous physical activity in people with cervical SCI such as joint injuries, hyperthermia or dehydration.

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