Wearable Sensors in Para-Sports

Subjects: Instruments & Instrumentation | Others

Contributor: Lorenzo Rum , Valentina Camomilla

Wearable sensors provide a promising opportunity to quantitatively assess the individual functional capacities of an athlete with disability in an ecological environment. The available evidence for the application of wearable sensors in sport for athletes with disabilities is mainly focused on performance assessment and characterization for training optimization, mirroring classic aspects of sports biomechanics in non-disabled athletes. Applications specific to sports for people with disability, such as athlete classification and injury prevention, are limited but indicate possible directions for further development. Finally, since the equipment is frequently of particular importance in sports for persons with disability, the literature indicates that wearable systems are promising to support the customization of equipment to meet the athlete's individual needs.

sport technology athletes biomechanics inertial sensors electromyography paralympic

1. Introduction

Over the last few years, the interest in sports for persons with disability has grown at an impressive rate. Simultaneously, the participation in sports by a growing number of persons with disabilities has been observed, with evidence showing the positive impact of sport on quality of life, physical health and psycho-social wellbeing in this population [1][2][3]. Given the large variety of disabilities and how they specifically affect and influence sports practice, advances in research and technology play a key role in providing tools for a safe, inclusive and effective participation in sport. To date, technology has been used to improve and support the athlete’s training and development in both elite and amateur sports for non-disabled and people with disabilities [4][5][6][7]. In the last decades, an increase in the application of wearable technologies in the sport field has been observed as they can be used with less restrictions compared to the other technological tools [4][8][9]. These technologies are adopted to measure different components of an athlete’s movement as well as to explore the relation between the athlete’s body and the sport equipment. Given their ecological and versatile properties, wearable sensors can provide objective measurement methods that can be applied in real sport-life situation and finely fit within several purposes. Aside from those general to all athletes population, the following aspects are specific to athletes with disabilities: athlete classification, sport equipment customization, and monitoring the athlete’s technique to prevent injury while designing successful training protocols.

Previous reviews on the applications of wearable technology in sports did not specifically focus on athletes with disabilities, providing more general indications on the topic [4][8][9]. Literature does however highlight wearable sensors advantages and potential to support athletes with disabilities at all athletic levels and in different application fields. Therefore, the aim of this review was to provide information to future researchers, athletes and trainers to support evidence-based practice by exploring literature regarding the use of wearable sensors in sport for people with disabilities.

2. Main findings

Sensor types and placements

The most commonly used wearable sensors were inertial and EMG sensors, often in conjunction with other types of sensors (e.g., force sensor, GPS, digital goniometer or heart rate sensor). This is in line with what already observed in similar sports biomechanics literature involving non-disabled athletes [8][9], likely because they allow measuring the biomechanical and physiological characteristics of performance in a more ecological setting. Furthermore, EMG or inertial sensors were frequently used in combination with video analysis and motion capture systems to take advantage of both measurement systems strengths, allowing to combine measurements of muscle activity or body/equipment motion with joint kinematics. A crucial aspect that limits the transversal interpretability of results is the lack of standardization in positioning. In wheelchair sports, as in other sports analyzed with inertial sensors, sensor positioning protocols is a prerogative of each research group. One reason for this is likely the limited number of studies performed on the same sport. In the studies adopting EMG sensors, motion tracking devices were fundamental for muscle activation pattern recognition and contextualization, providing kinematic information to obtain temporal events for the segmentation and analysis of the registered EMG signal. Specifically, video analysis [10][11][12], stereophotogrammetric systems [13][14] and other motion capture techniques [15][16] were used. Positioning of EMG sensors varied and was influenced by the observed sport activity and the specific purpose of the study, although particular attention was given to the investigation of trunk and upper limb muscles, which played a predominant role in determining performance as the majority of the reported disabilities affected the lower body. There is evidence that different combination of wearable sensors should be used to provide exhaustive and valuable information about sport performance increasing the possibility of obtaining biomechanical measurements in unusual outdoor conditions. Furthermore, the crucial role of kinetic quantities in performance analysis and injury prevention, especially in ecological conditions, calls for further research to overcome technical limitations allowing to explore the kinetic perspective.

Parameters and Application

Many of the applications of wearable sensors in sport biomechanics of non-disabled athletes that were indicated by previous reviews (i.e., injury prevention, performance characterization for training optimization) are applied to athletes with disabilities at a growing rate. In addition, new contexts of wearable technology application specific to sport for people with disability are reported, such as athlete classification and sports equipment customization.

Technology can provide the ideal tools for a more objective classification process for athletes with disability by assessing how sport performance is affected by the functional limitations descending from the impairment [17]. Only few studies were specifically performed to measure the effect of impairment on the athlete’s functional ability investigating features specific to the sport discipline, for example trunk strength in cross-country sit-skiing. EMG, inertial and force sensors were used to measure maximal capacity of force exertion and muscle activation, trunk segment range of motion and electromechanical delay between onset of muscle activation and motor task execution. These studies were not able to provide adequate athlete classification measurement systems, either because they did not show enough sensitivity to discriminate different sport classes or because of limited sample size. Nevertheless, these studies indicated the potential of the measured parameters for athlete classification that should be considered for future research on this topic. Furthermore, a common denominator across the papers dealing with athlete classification was the evaluation of the role of trunk in sport performance, as it plays an important role in force production and transmission during various propulsion-related sport activities, from wheelchair propulsion to sit-skiing.

Specific applications of wearable sensors in the analysis of sport technique aimed at injury prevention for people with disability were quite scarce. Furthermore, the few studies available in the literature differed for sports, sensors, injury types and study designs. Nevertheless, these papers were in line with recent investigation of the frequency, types and causes of injury in adaptive summer sports, such as wheelchair basketball, wheelchair rugby, swimming and athletics [18]. Similar types of injury can be found spanning across different sport disciplines, such as shoulder injury in wheelchair sport and in swimming. Therefore, athletes with different sport-related needs could transversely benefit from wearable systems that are able to monitor the kinematics and/or muscle activity of the shoulder, such as the one adopted in Barfield et al. [19]. In addition, other types of transversal injuries across sports like heat illness are caused by changes in physiological parameters (e.g., body temperature) that can be easily monitored through wearable sensors. However, extensive research on injury prevention through the use of wearable sensors in sport for people with disability is still missing. For all athletes, particular attention should be focused on the definition and selection of appropriate parameters, resolving the complexity of predictors of injury.

The most common application for wearable sensors in sport for people with disability was technique analysis for performance characterization, a trend that has been also reported in previous works on athletes without disability [4][8][9]. In sport for people with disability, studies explored classic aspects of sport biomechanics in non-disabled athletes, such as analysis of technique/performance, training load, biomechanical measurement system validation and comparison of data processing techniques, but also components more specific to the observed population, that is, for example, how a specific disability affects motor and sport performance. The effectiveness and appropriateness of current training practices in sport for people with disability have been questioned as there is a lack in research on sport-specific performance and development of athletes [20]. In the revised studies, wearable technologies were adopted to assess sport performance in a variety of different sports, with wheelchair propulsion and mobility tasks being the sport-related motor tasks of greatest interest. Inertial and heart rate sensors were used to monitor the overall physical activity during gameplays for the optimization of physical and technical training strategies in wheelchair court sports. Furthermore, inertial sensors were also used to obtain more specific kinematic parameters which are informative of the athlete’s wheelchair propulsion performance and technique. EMG sensors were found to offer the opportunity of monitoring the muscle activation patterns which are peculiar of propulsive technique, but also the change in muscle activity during wheelchair propulsion at different loads.

The example of wheelchair sports was only one of the possible applications of wearable sensors for training monitoring and optimization in athletes with disability, as demonstrated by the studies on other sports disciplines such as handcycling, cross-country sit-skiing and swimming. However, there are still some gaps in the available knowledge on the use of wearables that regards the scarcity of studies on specific sport disciplines and the lack of common evidence-based practice in the adoption of sensors in both research and daily sport activity.

An application of wearable sensors which was found to be specific to sport for people with disability was the evaluation of the effect of disability on the biomechanics and physiology of sport and motor performance. In four analyzed studies, the comparison between athletes with and without disability allowed for the identification of peculiar changes in motor performance which are implemented by the athletes to deal with the limitations imposed by the impairment [13][21][22][23]. In particular, wearable sensors such as EMG, force and heart rate sensors can be effectively adopted to assess muscle activity, power and fatigue when these aspects are of interest for the study of impairment. Wearable technologies would therefore offer the opportunity to compare athletes with and without disability in real sport-life conditions. This would provide information about the effect of specific impairment on motor control which is essential not only for advancing in the medical knowledge, but also for sport and rehabilitation professionals in order to personalize training protocols based on the individual specific strategies.

In common practice, sports equipment is customized to the needs of each specific athlete with disability and this procedure is typically performed with the help of skilled and experienced coaches. However, due to various reasons, not all athletes may have access to an experienced coach. There is some evidence pointing towards the possibility to use wearable sensors as a support for the adjustment of sport equipment, especially to assess the effect of different design parameters on wheelchair mobility performance. The enormous opportunity for the development of technologies that are capable of monitoring the sport performance in relation to the selection of safe and performance-enhancing sports equipment was also indicated in a recent review by Cooper et al. [24]. The authors also proposed the use of wearable IMU-based actigraphs to assess energy expenditure over time during wheelchair sport as a parameter to evaluate wheelchair configurations. Current literature on the use of wearable sensors for wheelchair customization suggests that other sport disciplines, such as rowing or archery, could benefit from the same application of wearable sensors.

3. Conclusions

Wearable sensors provide a promising opportunity to quantitatively assess the individual functional capacities of the athlete with disability in an ecological environment. The available evidence for the application of wearable sensors in sport for athletes with disabilities is mainly focused towards performance assessment in wheelchair sports. Main performance indicators included linear and rotational wheelchair accelerations and the amount of upper body muscle activity measured by inertial and EMG sensors, respectively. The available scientific literature concerning applications specific to sports for people with disability, such as athlete classification and injury prevention, although limited, shows a possible direction for further development. Future approaches in dealing with athlete classification and injury prevention should consider the definition of biomechanical and physiological parameters relevant to the athletic performance on a sport-specific basis and investigate their association with the functional limitations related to the type and severity of disability. Applications of wearables application in performance characterization for training optimization mirrored classic aspects of sport biomechanics in non-disabled athletes, but also investigated the effect of disability on sport performance. Although underexplored, this field of application is of particular interest for the community of coaches, trainers and athletes with disability as it can provide useful information for all the other above-mentioned contexts of application. Furthermore, acquiring additional knowledge about the athletic performance will help in translating current evidence from sports for non-disabled people to adapted sports. Finally, since the equipment is frequently of particular importance in sports for persons with disability, literature indicates that wearable systems are promising to support the customization of equipment to meet the athlete individual needs.

References

1. Saskia J. Te Velde; on behalf of the HAYS study group; Kristel Lankhorst; Maremka Zwinkels; Olaf Verschuren; Tim Takken; Janke De Groot; Associations of sport participation with self-perception, exercise self-efficacy and quality of life among children and adolescents with a physical disability or chronic disease—a cross-sectional study. *Sports Medicine - Open* **2018**, *4*, 1-11, 10.1186/s40798-018-0152-1.
2. J C Chawla; ABC of Sports Medicine: Sport for people with disability. *BMJ* **1994**, *308*, 1500-1504, 10.1136/bmj.308.6942.1500.
3. Florian Kiuppis; Inclusion in sport: disability and participation. *Sport in Society* **2016**, *21*, 4-21, 10.1080/17430437.2016.1225882.
4. Camomilla, V.; Bergamini, E.; Fantozzi, S.; Vannozzi, G. Trends Supporting the In-Field Use of Wearable Inertial Sensors for Sport Performance Evaluation: A Systematic Review. Sensors 2018, 18, 873.
5. Matsuwaka, S.T.; Latzka, E.W. Summer adaptive sports technology, equipment, and injuries. Sports Med. Arthrosc. Rev. 2019, 27, 48–55.
6. Burkett, B. Paralympic sports medicine—Current evidence in winter sport: Considerations in the development of equipment standards for Paralympic athletes. Clin. J. Sport Med. 2012, 22, 46–50.
7. Oh, H.; Johnson, W.; Syrop, I.P. Winter adaptive sports participation, injuries, and equipment. Sports. Med. Arthrosc. Rev. 2019, 27, 56–59.
8. Adesida, Y.; Papi, E.; McGregor, A.H. Exploring the role of wearable technology in sport kinematics and kinetics: A systematic review. Sensors 2019, 19, 1597.
9. Taborri, J.; Keogh, J.; Kos, A.; Santuz, A.; Umek, A.; Urbanczyk, C.A.; van der Kruk, E.; Rossi, S. Sport Biomechanics Applications Using Inertial, Force, and EMG Sensors: A Literature Overview. Appl. Bionics Biomech. 2020, 2020, 2041549.
10. Louise C. Mâsse; Mario Lamontagne; Micheal D. O'riain; Biomechanical analysis of wheelchair propulsion for various seating positions. *The Journal of Rehabilitation Research and Development*

1992, *29*, 12-28, 10.1682/jrrd.1992.07.0012.

11. John W Chow; Tim A Millikan; Les G Carlton; Woen-Sik Chae; Marty I Morse; Effect of resistance load on biomechanical characteristics of racing wheelchair propulsion over a roller system. *Journal of Biomechanics* **2000**, *33*, 601-608, 10.1016/s0021-9290(99)00211-0.
12. John W. Chow; Tim A. Millikan; Les G. Carlton; Marty I. Morse; Woen-Sik Chae; Biomechanical comparison of two racing wheelchair propulsion techniques. *Medicine & Science in Sports & Exercise* **2001**, *33*, 476-484, 10.1097/00005768-200103000-00022.
13. W. Lee Childers; Boris I. Prilutsky; Robert J. Gregor; Motor adaptation to prosthetic cycling in people with trans-tibial amputation. *Journal of Biomechanics* **2014**, *47*, 2306-2313, 10.1016/j.jbiomech.2014.04.037.
14. Arnaud Faupin; Philippe Gorce; Eric Watelain; Christophe Meyer; Andre Thevenon; A Biomechanical Analysis of Handcycling: A Case Study. *Journal of Applied Biomechanics* **2010**, *26*, 240-245, 10.1123/jab.26.2.240.
15. Oliver J. Quittmann; Thomas Abel; Kirsten Albracht; Joshua Meskemper; Tina Foitschik; Heiko K. Strüder; Biomechanics of handcycling propulsion in a 30-min continuous load test at lactate threshold: Kinetics, kinematics, and muscular activity in able-bodied participants. *European Journal of Applied Physiology* **2020**, *120*, 1403-1415, 10.1007/s00421-020-04373-x.
16. Yu-Sheng Yang; Alicia M. Koontz; Ronald J. Triolo; Jennifer L. Mercer; Michael L. Boninger; Surface electromyography activity of trunk muscles during wheelchair propulsion. *Clinical Biomechanics* **2006**, *21*, 1032-1041, 10.1016/j.clinbiomech.2006.07.006.
17. S. M. Tweedy; Y. C. Vanlandewijck; International Paralympic Committee position stand--background and scientific principles of classification in Paralympic sport. *British Journal of Sports Medicine* **2009**, *45*, 259-269, 10.1136/bjsm.2009.065060.
18. Sean T. Matsuwaka; Erek W. Latzka; Summer Adaptive Sports Technology, Equipment, and Injuries. *Sports Medicine and Arthroscopy Review* **2019**, *27*, 48-55, 10.1097/jsa.0000000000000231.
19. Jp Barfield; Laura Newsome; Emmanuel B John; David Sallee; Chris Frames; Rahul Soangra; Laurie A Malone; A case report of shoulder fatigue imbalance in wheelchair rugby: implications to pain and injury. *Spinal Cord Series and Cases* **2016**, *2*, 16002, 10.1038/scsandc.2016.2.
20. Nima Dehghansai; Srdjan Lemez; Nick Wattie; Joseph Baker; A Systematic Review of Influences on Development of Athletes With Disabilities. *Adapted Physical Activity Quarterly* **2017**, *34*, 72-90, 10.1123/apaq.2016-0030.
21. Phoebe Runciman; Wayne Derman; Suzanne Ferreira; Yumna Albertus-Kajee; Ross Tucker; A Descriptive Comparison of Sprint Cycling Performance and Neuromuscular Characteristics in

Able-Bodied Athletes and Paralympic Athletes with Cerebral Palsy. *American Journal of Physical Medicine & Rehabilitation* **2015**, *94*, 28-37, 10.1097/phm.0000000000000136.

22. Phoebe Runciman; Ross Tucker; Suzanne Ferreira; Yumna Albertus-Kajee; Wayne Derman; Effects of Induced Volitional Fatigue on Sprint and Jump Performance in Paralympic Athletes with Cerebral Palsy. *American Journal of Physical Medicine & Rehabilitation* **2016**, *95*, 277-290, 10.1097/phm.0000000000000372.
23. P. Runciman; R. Tucker; S. Ferreira; Y. Albertus-Kajee; W. Derman; Paralympic athletes with cerebral palsy display altered pacing strategies in distance-deceived shuttle running trials. *Scandinavian Journal of Medicine & Science in Sports* **2015**, *26*, 1239-1248, 10.1111/sms.12575.
24. Rory A. Cooper; Yetsa A. Tuakli-Wosornu; Geoffrey V. Henderson; Eleanor Quinby; Brad E. Dicianno; Kalai Tsang; Dan Ding; Rosemarie Cooper; Theresa M. Crytzer; Alicia M. Koontz; et al.Ian RiceAdam W. Bleakney Engineering and Technology in Wheelchair Sport. *Physical Medicine and Rehabilitation Clinics of North America* **2018**, *29*, 347-369, 10.1016/j.pmr.2018.01.013.
25. Micera, S.; Vannozzi, G.; Sabatini, A.; Dario, P. Improving detection of muscle activation intervals. IEEE Eng. Med. Biol. Mag. 2001, 20, 38–46.
26. International Paralympic Committee. IPC Athlete Classification Code; International Paralympic Committee: Bonn, Germany, 2015.
27. Tweedy, S.; Vanlandewijck, Y. International Paralympic Committee Position Stand—Background and scientific principles of Classification in Paralympic Sport. Br. J. Sports Med. 2009.
28. Cooper, R.A.; Tuakli-Wosornu, Y.A.; Henderson, G.V.; Quinby, E.; Dicianno, B.E.; Tsang, K.; Ding, D.; Cooper, R.; Crytzer, T.M.; Koontz, A.M.; et al. Engineering and technology in wheelchair sport. Phys. Med. Rehabil. Clin. 2018, 29, 347–369.
29. Vellios, E.E.; Pinnamaneni, S.; Camp, C.L.; Dines, J. Technology Used in the Prevention and Treatment of Shoulder and Elbow Injuries in the Overhead Athlete. Curr. Rev. Musculoskelet. Med. 2020, 13, 472–478.
30. Willy, R.W. Innovations and pitfalls in the use of wearable devices in the prevention and rehabilitation of running related injuries. Phys. Ther. Sport 2018, 29, 26–33.
31. Florian Kiuppis; Inclusion in sport: disability and participation. *Sport in Society* **2016**, *21*, 4-21, 10.1080/17430437.2016.1225882.
32. Louise C. Mâsse; Mario Lamontagne; Micheal D. O'riain; Biomechanical analysis of wheelchair propulsion for various seating positions. *The Journal of Rehabilitation Research and Development* **1992**, *29*, 12-28, 10.1682/jrrd.1992.07.0012.

33. John W Chow; Tim A Millikan; Les G Carlton; Woen-Sik Chae; Marty I Morse; Effect of resistance load on biomechanical characteristics of racing wheelchair propulsion over a roller system. *Journal of Biomechanics* **2000**, *33*, 601-608, 10.1016/s0021-9290(99)00211-0.
34. John W. Chow; Tim A. Millikan; Les G. Carlton; Marty I. Morse; Woen-Sik Chae; Biomechanical comparison of two racing wheelchair propulsion techniques. *Medicine & Science in Sports & Exercise* **2001**, *33*, 476-484, 10.1097/00005768-200103000-00022.
35. W. Lee Childers; Boris I. Prilutsky; Robert J. Gregor; Motor adaptation to prosthetic cycling in people with trans-tibial amputation. *Journal of Biomechanics* **2014**, *47*, 2306-2313, 10.1016/j.jbiomech.2014.04.037.
36. Arnaud Faupin; Philippe Gorce; Eric Watelain; Christophe Meyer; Andre Thevenon; A Biomechanical Analysis of Handcycling: A Case Study. *Journal of Applied Biomechanics* **2010**, *26*, 240-245, 10.1123/jab.26.2.240.
37. Oliver J. Quittmann; Thomas Abel; Kirsten Albracht; Joshua Meskemper; Tina Foitschik; Heiko K. Strüder; Biomechanics of handcycling propulsion in a 30-min continuous load test at lactate threshold: Kinetics, kinematics, and muscular activity in able-bodied participants. *European Journal of Applied Physiology* **2020**, *120*, 1403-1415, 10.1007/s00421-020-04373-x.
38. Yu-Sheng Yang; Alicia M. Koontz; Ronald J. Triolo; Jennifer L. Mercer; Michael L. Boninger; Surface electromyography activity of trunk muscles during wheelchair propulsion. *Clinical Biomechanics* **2006**, *21*, 1032-1041, 10.1016/j.clinbiomech.2006.07.006.
39. S. M. Tweedy; Y. C. Vanlandewijck; International Paralympic Committee position stand--background and scientific principles of classification in Paralympic sport. *British Journal of Sports Medicine* **2009**, *45*, 259-269, 10.1136/bjsm.2009.065060.
40. Valeria Rosso; Laura Gastaldi; Walter Rapp; Stefan Lindinger; Yves Vanlandewijck; Sami Äyrämö; Vesa Linnamo; Balance Perturbations as a Measurement Tool for Trunk Impairment in Cross-Country Sit Skiing. *Adapted Physical Activity Quarterly* **2019**, *36*, 61-76, 10.1123/apaq.2017-0161.
41. Sean T. Matsuwaka; Erek W. Latzka; Summer Adaptive Sports Technology, Equipment, and Injuries. *Sports Medicine and Arthroscopy Review* **2019**, *27*, 48-55, 10.1097/jsa.0000000000000231.
42. Jp Barfield; Laura Newsome; Emmanuel B John; David Sallee; Chris Frames; Rahul Soangra; Laurie A Malone; A case report of shoulder fatigue imbalance in wheelchair rugby: implications to pain and injury. *Spinal Cord Series and Cases* **2016**, *2*, 16002, 10.1038/scsandc.2016.2.
43. Nima Dehghansai; Srdjan Lemez; Nick Wattie; Joseph Baker; A Systematic Review of Influences on Development of Athletes With Disabilities. *Adapted Physical Activity Quarterly* **2017**, *34*, 72-90, 10.1123/apaq.2016-0030.

44. Phoebe Runciman; Wayne Derman; Suzanne Ferreira; Yumna Albertus-Kajee; Ross Tucker; A Descriptive Comparison of Sprint Cycling Performance and Neuromuscular Characteristics in Able-Bodied Athletes and Paralympic Athletes with Cerebral Palsy. *American Journal of Physical Medicine & Rehabilitation* **2015**, *94*, 28-37, 10.1097/phm.0000000000000136.
45. Phoebe Runciman; Ross Tucker; Suzanne Ferreira; Yumna Albertus-Kajee; Wayne Derman; Effects of Induced Volitional Fatigue on Sprint and Jump Performance in Paralympic Athletes with Cerebral Palsy. *American Journal of Physical Medicine & Rehabilitation* **2016**, *95*, 277-290, 10.1097/phm.0000000000000372.
46. P. Runciman; R. Tucker; S. Ferreira; Y. Albertus-Kajee; W. Derman; Paralympic athletes with cerebral palsy display altered pacing strategies in distance-deceived shuttle running trials. *Scandinavian Journal of Medicine & Science in Sports* **2015**, *26*, 1239-1248, 10.1111/sms.12575.
47. Rory A. Cooper; Yetsa A. Tuakli-Wosornu; Geoffrey V. Henderson; Eleanor Quinby; Brad E. Dicianno; Kalai Tsang; Dan Ding; Rosemarie Cooper; Theresa M. Crytzer; Alicia M. Koontz; et al.Ian RiceAdam W. Bleakney Engineering and Technology in Wheelchair Sport. *Physical Medicine and Rehabilitation Clinics of North America* **2018**, *29*, 347-369, 10.1016/j.pmr.2018.01.013.