

## Kinematic bidimensional analysis of the propulsion technique in wheelchair rugby athletes

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### Abstract

Wheelchair rugby is a sport ideated for individuals with cervical spinal cord injury (CSCI) which is extremely important for maintaining their neuromuscular abilities and improving their social and psychological wellbeing. However, due to the frequent changes in direction and speed it considerably stresses the players' upper limbs. 13 athletes have undergone two sports-related tests on an inertial drum bench and several kinematic parameters have been registered. Most athletes use a semi-circular pattern which is considered protective for the upper limb. With increasing speed, range of motion (ROM) increases. Release angles increment and contact angles reduce, displacing the push angle forward to increase speed. Instead, the more anterior late push angle used to increase velocity is a factor which further loads the shoulder joint. However, other factors affecting propulsion technique, such as posture and wheelchair set up should be studied to further reduce loading on the upper limb.

**Key Words:** propulsion kinematics, Paralympic sports, elite athletes, wheelchair rugby, wheelchair propulsion

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Wheelchair rugby (WRugby) was developed in Canada in the 1970's by athletes with quadriplegia. It is a Paralympic team sport since Sydney 2000 Para Games.<sup>1</sup> It's well known that staying active after a Spinal Cord Injury (SCI) is important for maintaining physical capacity, but also for mental and emotional well-being.<sup>2</sup> Evidence shows that regular physical activity is an effective way of improving fitness in the SCI population as well as promoting functional independence.<sup>3</sup> Patients' perceived benefits of sports activity include a feeling of increased fitness, increased social interactions, improved quality of life, muscle strength and confidence and better physical recovery.<sup>4</sup> Sports practice represents a risk factor for both overuse and trauma disorders, especially to the upper limbs, that are used for all their daily life activities. The repeated performance of upper limb, weight-bearing activities such as wheelchair propulsion, transfers, and raised ischial pressure reliefs ("weight shifts"), as well as reaching from a seated position in the wheelchair in environments designed for nondisabled individuals, places a great deal of stress on the bones, joints, and soft tissues of the shoulder complex, placing these structures at significant risk for overuse and injury.<sup>5</sup>

Wheelchair rugby a discipline with high risk of injury. Indeed it resulted as fifth most injury-prone sport in the London 2012 Summer Paralympic game.<sup>6</sup> Biomechanical research is considered a very important contribute to performance and athlete wellbeing as it gains insight in technical optimization, injury prevention and classification in Paralympic sports.<sup>7</sup> Many researchers have studied the biomechanical factors and underlying musculature involved during standard wheelchair propulsion,<sup>8</sup> whereas the propulsion technique used during sports such as wheelchair rugby is still being investigated. We here report preliminary results of a project conducted by an interdisciplinary research team of professionals which included doctors, physiotherapists, engineers, psychologists and physical education students. Aim of study was the evaluation of the propulsion kinematic and wheelchair propulsion characteristics among the athletes of the Italian National Wheelchair rugby team.<sup>9</sup>

### Materials and Methods

The subjects included were 13 athletes from the Italian National Wheelchair rugby team in which 12 had Spinal

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Table 1: Subject presentation

Athlete	Classification Points (level of disability)	Pathology	Lesion level	Sprint test	Wingate test	Motion Capture	Athlete comparison
P.S.	0.5	SCI	C5-C6	x	x		x
A.F.	0.5	SCI	C5	x	x	x	x
P.F.	1	SCI	C5-C6		x		x
H.K.	1	SCI	C5-C6	x	x	x	x
G.T.	1	SCI	C6-C7		x		x
S.P.	1.5	SCI	C6	x	x		x
A.D.	1.5	SCI	C7	x	x		x
D.G.	1.5	SCI	C6-C7	x	x	x	x
L.V.	2.5	SCI	C5-C7		x		x
M.B.	2.5	SCI	C7-T1	x	x	x	
N.T.	3.0	SCI	C7		x		x
A.B.	3.5	SCI	T6-T7	x	x	x	
P.M.	3.5	Cerebral Palsy	-	x	x	x	

Cord Injury (SCI) and 10 had Cervical Spinal Cord Injury (CSCI). Table 1 displays the tests available for each subject and specific information for each athlete. The level of disability was evaluated using the sport classification (IWRF 2005-2017).

### Instrumentation and tests

- An inertial drum bench
- BTS Bioengineering Smart DX-6000 Optoelectronics MotionCapture 3D system with 8 infrared cameras.
- A Canon Powershot SX240 HS camera
- Computer software Kinovea, 0.8.25.0 version for Windows was used to analyze the videos taken of the athletes during the tests' execution.

Athletes carried out 2 sports-specific *dynamic tests* on the drum bench:

- Sprinting test over 20 meters, measured using the drum bench
- Wingate test10: a sprint test with an applied resistance exerted by the drum bench.

All tests were carried out on the athletes' personal rugby wheelchair. Athletes were filmed as they performed the tests. Data analysis were analyzed with Kinovea software. Three push cycles were chosen (one at beginning, one in the middle and one at the end of the test) to have an example of the propulsive stroke at the different speeds obtained in the sprint test. For each video the following parameters were considered:

- “Absolute arm angle”: the angle comprised by the segment built on the arm with the vertical line originating from the elbow marker.
- “Arm to forearm angle”: the angle made up by the arm and forearm created by elbow flexion and extension.
- “Elbow flexion angle”
- “Contact angle” (Figure 1a)
- “Release angle” (Figure 1b)
- “Total Push angle” (Figure 1c)

Each of these parameters was taken for every frame of the video throughout the whole push cycle and recorded on an Excel worksheet.

### Comparison between athletes

The results for absolute arm angle and elbow flexion were compared amongst different athletes for each part of each test: sprint start, sprint midway, sprint end, Wingate start, Wingate midway and Wingate end. Graphs were plotted of the angles indicating the flexion-extension pattern used by the different athletes in each part of the test, differentiating between Sprint and Wingate. Furthermore, numerical values of maximum, minimum and mean elbow flexion and extension values at start, middle and final parts of Wingate and Sprint tests were compared amongst different athletes. Similarly, contact, release and total push angles were compared between different athletes. All calculations were done using Excel computer software for Windows.

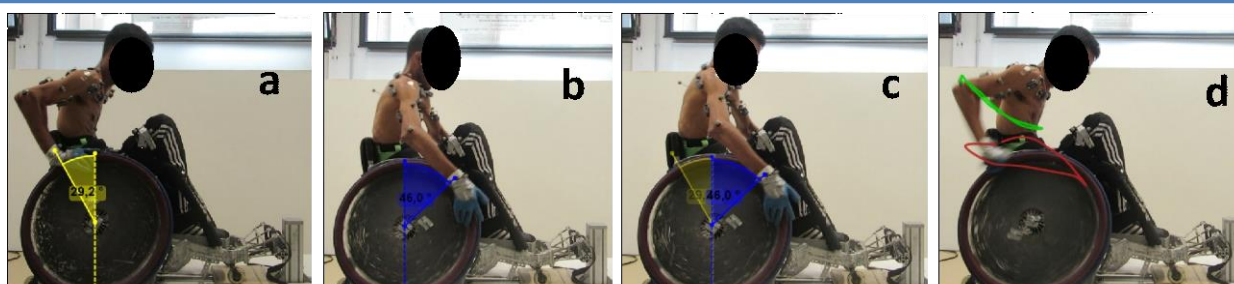
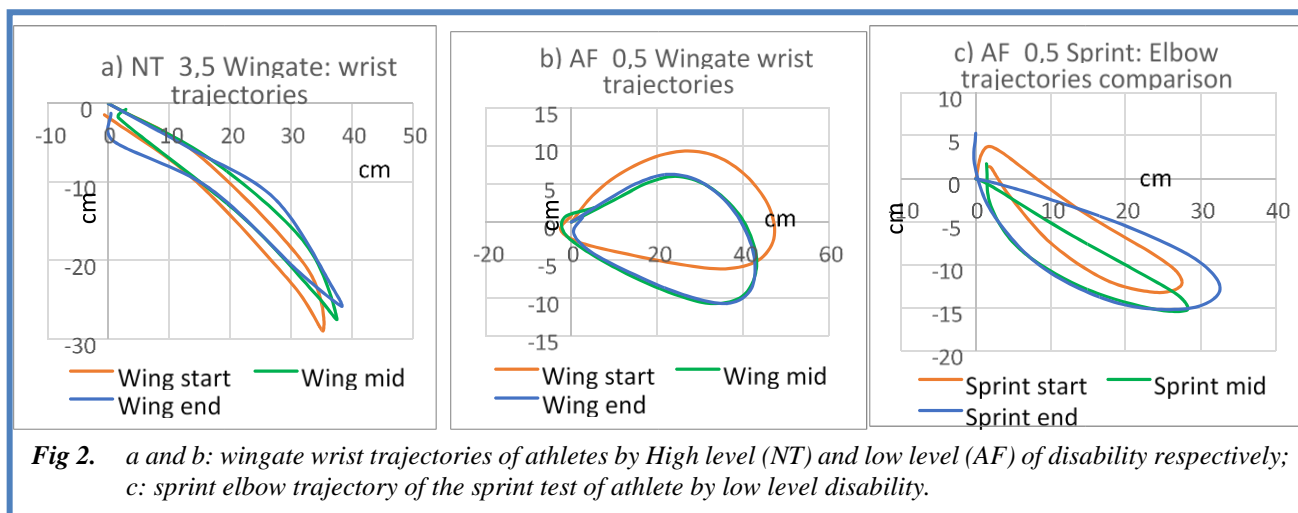


Fig 1. a: contact angle; b: release angle, c: total push angle, d: wrist (red) and elbow (green) trajectories

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### Results and Discussion

Athletes' analyses are reported in Figure 2.

#### Trajectories

Most athletes used a propulsion technique that reminds of the semi-circular pattern,<sup>11</sup> particularly those with greater levels of disability. This suggests that it is the easiest to achieve and requires less motor control. Furthermore, it allows to use a greater portion of the push rim to carry out the stroke and reach a considerable speed by spreading the force applied on a greater surface. Its elliptical shape reduces the stress applied to the joints as it doesn't include abrupt changes in direction: it is in fact considered the most protective for the upper limb. Players with greater motor abilities tend to use the arching pattern which is more efficient and includes a sharp alternation of flexion and extension. The well-defined trajectory suggests the need for greater muscle coordination and precision in muscle activation and control to maintain the strict flexion-extension pattern. However, this modality is associated to abrupt changes in direction which are considered stressful to the upper extremity joints.<sup>11</sup>

#### Sprint test

Overall ROM at the elbow increases for most athletes from the start ( $68,4^\circ \pm 14,3^\circ$ ) to the end ( $76^\circ \pm 10,98^\circ$ ). Lower-classified players exhibit rather small peak extension values and greater elbow flexion values whereas subjects with higher classification scores use progressively greater elbow extension and less elbow flexion. This can be explained by the fact that low-point subjects with lesion level C5 or C5-C6 are unable or only partially capable of recruiting the triceps and tend to use greater elbow flexion at the start of the push phase to maximize biceps function.<sup>12</sup> In contrast, players with better motor function utilize a smaller elbow flexion at initial contact and probably use a forward displacement of the trunk to aid the propulsion technique. This is consistent with the lesion level and a greater muscle

recruitment on the upper trunk.<sup>12</sup> According to Van der Woude et al. studies, a range between  $94^\circ$  and  $143^\circ$  of elbow flexion is effective in giving ideal long, smooth strokes in normal wheelchair users.<sup>13</sup> The athletes analyzed, though, use largely smaller elbow extension and greater elbow flexion, for an overall range between  $43,1^\circ \pm 4,52^\circ$  and  $116,8^\circ \pm 0,79^\circ$ . This is probably given by their inability to recruit upper-limb distal muscles, especially the triceps.

#### Wingate test

The range of motion seems to vary less in amplitude compared to sprint test ( $75,9^\circ \pm 18,68^\circ$  at the start,  $74,7^\circ \pm 18,1^\circ$  at the end), probably due to a greater difficulty in overcoming the additional resistance applied. The most significant finding was that there is a great variability between athletes in the strategies used to overcome this resistance: most subjects display an increase in ROM between the start and the middle of the test, probably due to muscular and cardiovascular fatigue; some displayed a decrease with a consequent increase in ROM which might be caused by an initial difficulty in accelerating and overcoming the resistance at the same time. The overall mean percentage time spent pushing during Wingate, 50,1%, was greater than the percentage push phase of the Sprint test, 44,4%: at the start the percentage time spent pushing is similar in both tests, it then decreases throughout the test but during the Sprint test the decrease is larger. Furthermore, two subjects changed their style of push: one from semi-circular to double-loop-over and the second from semi-circular to arcing pattern. While the first subject has a greater level of disability and exhibits this change both in Wingate and Sprint tests, suggesting this is a strategy used to increase speed; the second only changes to arcing pattern in the sprint test, suggesting the semi-circular pattern is more useful when having to overcome higher loads and maintain a high speed at the same time.

#### Push and contact angles

In the sprint test there seems to be an overall increase in

release angles with a mean increment of  $8,5^{\circ} \pm 3,7^{\circ}$  and reduction in contact angles of an average of  $9,1^{\circ} \pm 5,2^{\circ}$  resulting in an overall increase in total push angles which is consistent with Haydon et al. study.<sup>11</sup> During the Wingate test, instead, contact angles seem to remain similar, with a decrease, at the end of the test of contact, release and total push angles. This might be a strategy to achieve a greater velocity during wheelchair propulsion. Absolute arm angles also remain rather similar with a mean ROM of  $82,1^{\circ} \pm 15,5^{\circ}$  and  $82,25^{\circ} \pm 14,35^{\circ}$  at start and end. Unfortunately, this condition has been related to a higher amount of forces exerted on the shoulder<sup>14</sup>. An efficient sprinting technique is very important in wheelchair rugby as it allows to reach quickly the opposing team's line to score points, however it is in contrast with shoulder pain prevention.

In conclusion, the results obtained allowed the identification of diversities amongst athletes with different neuromuscular abilities and the overall techniques used to perform sports tasks. The study reveals that most wheelchair rugby athletes use a semi-circular style of push, especially lower point players. In literature this is regarded as the least dangerous technique for upper limb disorders. High point players tend to use an arcing pattern and more anteriorly displaced angles that promote a faster speed but are potentially damaging. Prevention should stand on compromise between protective technique and best sport performance. Since the results reported in this first report are very interesting, it will be worth to involve a greater number of athletes in the following phases of the project.

### List of acronyms

CSCI - cervical spinal cord injury  
IWRF - International Wheelchair Rugby Federation  
ROM - range of motion  
SCI - Spinal Cord Injury  
WRugby - Wheelchair rugby

### Authors contributions

SMF and FG document production and clinical evaluation; MT clinical analysis; MB, GM, FB and PS kinematic analysis and test assessment; MA, NP and SM study conception and critical revision.

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### Conflict of Interest

The authors declare they have no financial, personal, or other conflicts of interest.

### Ethical Publication Statement

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

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