



HAL
open science

Trying to use temporal and kinematic parameters for the classification in wheelchair badminton

Ilona Alberca, Bruno Watier, Félix Chénier, Florian Brassart, Mélanie Bacconnais, Bryan Le Toquin, Imad Hamri, Jean-Marc Vallier, Arnaud Faupin

► **To cite this version:**

Ilona Alberca, Bruno Watier, Félix Chénier, Florian Brassart, Mélanie Bacconnais, et al.. Trying to use temporal and kinematic parameters for the classification in wheelchair badminton. 2024. hal-04830088

HAL Id: hal-04830088

<https://hal.science/hal-04830088v1>

Preprint submitted on 10 Dec 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Trying to use temporal and kinematic parameters for the classification in wheelchair badminton

Iloa Alberca^{1*}, Bruno Watier^{2,3}, Félix Chénier^{4,5}, Florian Brassart¹, Mélanie Baconnais⁶, Bryan Le Toquin⁶,
Imad Hamri⁶, Jean-Marc Vallier¹, and Arnaud Faupin¹

¹Laboratoire J-AP2S, Université de Toulon, La Garde, France ; ²LAAS-CNRS, Université de Toulouse, CNRS, UPS, Toulouse, France ; ³CNRS-AIST JRL (Joint Robotics Laboratory), IRL, National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Umezono, 305-8560 Tsukuba, Ibaraki, Japan ; ⁴Mobility and Adaptive Sports Research Lab, Department of Physical Activity Sciences, Université du Québec à Montréal, Montreal, QC, Canada, ⁵Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal, Institut Universitaire sur la Réadaptation en Déficience Physique de Montréal, Montreal, QC, Canada ; ⁶Institut de Recherche Bio-Médicale et d'Épidémiologie du Sport (IRMES), EA 7329, Institut National du Sport, de l'Expertise et de la Performance (INSEP), Paris, France.

Abstract:

Introduction: This study explores the potential for the temporal and kinematic datas link to propulsion technique and athlete performance collected here to contribute to evidence-based classification for wheelchair badminton athletes. **Materials and Methods:** Nineteen experienced wheelchair badminton players underwent propulsion tests with a badminton racket. Wheelchair were equipped with inertial measurement units. The first analysis conducted involved comparing the parameters between class WH1 and WH2. Subsequently, a hierarchical clustering analysis was performed on the parameters with significant differences. **Results:** Regarding propulsion technique parameters, WH1 athletes exhibit a longer braking phase compared to WH2 athletes. Generally, the performance of WH1 athletes is inferior to that of WH2 athletes. Concerning hierarchical clustering analysis, the results reveal the formation of three clusters based on principal components explaining 70% of the variation in the parameters considered in the analysis. **Conclusion:** Thus, the results of this study indicate a longer braking time for WH1 athletes compared to WH2, along with lower overall performance. The clusters results could suggest a potential evolution of the current classification towards three distinct classes of wheelchair badminton players. However, these findings should be interpreted with caution, given that the included performance parameters can be influenced by numerous factors, potentially undermining the robustness of the clustering methodology employed. This study highlights the need to strengthen the current classification process in wheelchair badminton.

Key words: wheelchair; badminton; biomechanics; classification; impairment; cluster

1 Introduction

2 Classification of athletes is paramount in wheelchair sports, including badminton,
3 aiming to allocate athletes into appropriate sport classes to minimize the influence of
4 impairment on competition outcomes while prioritizing sporting excellence (1). As
5 emphasized by Goosey-Tolfrey and Leitch (2), classification reflects the individual's level of
6 disability. Following the functional classification system proposed by Strohkendl in 1982,
7 endorsed by the International Wheelchair Basketball Federation, wheelchair badminton
8 employs a similar approach, assessing athletes' functional abilities for classification purposes
9 (3). Specifically, they are classified into two classes: WH1 and WH2. WH1 athletes are
10 manual wheelchair users with abdominal and lower limb paralysis, while WH2 participants
11 possess abdominal capabilities but experience lower limb paralysis with partial sensation (4).

12 Given the novelty of the sport, wheelchair badminton classification was recently
13 established by the International Paralympic Committee Athlete Classification Code in 2015.
14 The classification process is initiated by determining eligibility based on a Minimal
15 Impairment Criteria (MIC), as described by the BWF (3). Once this step is completed, a
16 physical evaluation is conducted, which includes a manual muscle test (5) and/or a joint
17 mobility test (5). The ASIA score should be used for athletes with spinal cord injuries (3,6).
18 Finally, after the physical evaluation, a technical assessment is carried out during a
19 tournament and a training match, where evaluators are asked to identify the following
20 profiles:

- 21 - WH1: "Players exhibit functional limitations based on muscle power and trunk range
22 of motion, and possibly upper limbs, during a match or training session" (3).
- 23 - WH2: "Players have a functional limitation based on reduced muscle power or range
24 of motion, requiring the use of mobility aids. Shifting the center of gravity may result
25 in loss of balance, for example, when attempting to pivot or during stop-and-start
26 movements" (3).

27 This final assessment may include an evaluation of the player's ability to perform
28 specific tasks and activities that are part of wheelchair badminton (3).

29 However, this classification process does not involve any objective measurement of the
30 athletes' performance capabilities. The International Paralympic Committee (IPC) has
31 established the conceptual framework of evidence-based classification for several years (7).
32 Recent studies have explored the use of data-driven approaches to improve classification in
33 wheelchair sports. Inertial sensor technology and standardized field tests have been shown to
34 provide objective measures of wheelchair mobility performance, potentially reducing the
35 number of classes in wheelchair basketball (8). Cluster analysis of isometric strength tests has
36 produced valid classification structures for wheelchair track racing, offering a more
37 transparent and less subjective system (9). In wheelchair rugby, trunk strength impairment has
38 been correlated with specific performance determinants, and cluster analysis has supported
39 the concept of "natural classes" based on how trunk muscle strength affects activities (10).
40 These data-driven approaches show promise in enhancing the validity and objectivity of
41 classification in wheelchair sports. Based on the study by Tweedy & Vanlandewijck (7),
42 incorporating such parameters into the evidence-based classification process could correspond
43 to "Step 3b: Develop measures of (determinants of) performance". Notably, the integration of
44 inertial measurement units (IMUs) has recently facilitated the acquisition of on-field
45 performance data for wheelchair athletes (11). In a manuscript in pre-print and currently
46 under submission, Alberca et al. (12), recently utilized two IMUs placed on the wheels of the
47 wheelchair to assess diverse performance parameters among wheelchair badminton players

48 during a one-minute field test (forward and backward propulsion test reproducing the
49 movements of wheelchair badminton players).

50 Hence, the main aim of this study is to explore the potential for the temporal and
51 kinematic data link to propulsion technique and athlete performance collected to contribute to
52 evidence-based classification for wheelchair badminton athletes. To meet this main objective,
53 it will first be necessary to examine whether classification has an impact on these same
54 temporal and kinematic parameters. For individuals with spinal cord injuries, the level of the
55 lesion significantly impacts postural stability and propulsion abilities, particularly in the
56 abdominal region, leading to expected performance differences between WH1 and WH2
57 athletes, as evidenced by studies showing variations in match intensity and shots played (13–
58 18). Thus, it can be hypothesized that WH1 athletes with more severe functional limitations
59 will demonstrate temporal and kinematic patterns indicative of lower performance compared
60 to WH2 athletes with lower velocities, acceleration, deceleration and longer sprint time.
61 Additionally, it is hypothesized that the temporal and kinematic parameters measured in this
62 study correctly discriminate the two classes of wheelchair badminton athlete.

63 **Materials and methods**

64 *Study design*

65 This study aims to explore the possibility that the temporal and kinematic data
66 representative of propulsion technique and athlete performance from this study could serve as
67 evidence for the evidence-based classification. Warmed-up participants performed
68 consecutive forward and backward sprints over 3 m for 1 min to carry out a test as close as
69 possible to match conditions as shown in Figure 1 (12). The duration of 1 min and the length
70 of 3 m of the test were chosen to correspond to the characteristics of this sport without
71 inducing too intense an effort for the athletes (court size: 3.96 m long and effective playing
72 time: 5.7 min and 7.7 min) (17).

73 **[Figure 1]**

74 **Figure 1:** Schematic diagram of forward/backward propulsion test

75 During the experiment, all athletes started from a stationary position at the 3-meter line,
76 demarcated by cones, initiating in forward propulsion. Subsequently, they braked and
77 proceeded in backward propulsion along the same course, repeating this sequence for 1 min.
78 When switching between propulsion directions, athletes were required to pass the large
79 wheels of their wheelchairs beyond the cones at each end of the track. Two trials were
80 conducted for each participant: one with the racket and one without, with the trial order
81 determined randomly (12). The badminton racket and wheelchair utilized were individualized
82 to each participant and matched those employed in competitions. The athletes' personal
83 wheelchairs featured camber angles ranging from 18° to 20°, with wheel sizes ranging from
84 24 to 26 inches and a rear anti-tip wheel. Each athlete held the racket on their preferred side,
85 referred to as the racket side. A 5-minute break was kept between each trial. Although the
86 propulsion technique was not prescribed, upon observation, all athletes employed
87 synchronous propulsion.

88 *Ethics*

89 The data of this study were collected during the French Championships of Nueil-les-
90 Aubiers from 14 to 16 January 2022 and Saint-Orens from 13 to 15 January 2023. The
91 experimental protocol was approved by the Comité d’Ethique pour les Recherches en STAPS
92 (CERSTAPS) from Conseil National des Universités de France [certificate #CERSTAPS

93 **IRB00012476-2021-11-06-274]** filed on February 2021 and accepted on Jun 2021.
94 Participants were recruited starting on December 1, 2021, and end on January 10, 2022. All
95 participants have received and signed a written informed consent and information notice.

96 ***Participants***

97 A total of 19 wheelchair badminton athletes was included in this study. Inclusion
98 criteria required participants to be at a national level or higher in wheelchair badminton and
99 have a minimum of one year of experience in playing the sport. Participants were excluded if
100 they reported any pain or injury that could hinder their ability to propel their wheelchair. To
101 determine the minimum sample size required for this study, a statistical power test has been
102 made with de Rhodes et al. (19) as the reference article. The required sample size was
103 estimated at N = 16 participants. Considering this result, a total of N = 19 badminton athletes
104 was included in this analysis. Statistical power testing was performed using G*Power
105 software (G*Power, 2020; g-power.apponic.com). Characteristics of all participants are

	Gender	Class	Age (years)	Body height (cm)	Body mass (kg)	BMI (kg/m²)	Years of practice (years)	Racket side	Health condition	Wheelchair Camber (°)	Wheel size (inch)
1	Female	WH2	55	162	60	22,86	9	R	Paraplegia (T12-L1)	20	24
2	Female	WH1	45	165	58	21,30	10	R	Paraplegia (T6-T8)	18	25
3	Male	WH2	31	180	60	18,52	6	L	Paraplegia (T12-L1)	18	26

106 presented in Table 1.

4	Male	WH1	37	176	67	21,63	6	R	Paraplegia (T7-T8)	20	25
5	Male	WH1	45	158	64	25,64	17	R	Spinabifida	18	25
6	Male	WH2	48	187	75	21,45	9	R	Paraplegia (T12)	20	26
7	Female	WH1	53	171	68	23,26	8	R	Paraplegia (T12-L1)	20	25
8	Male	WH1	45	168	71	25,16	12	R	Paraplegia (T5-T6)	20	25
9	Female	WH1	33	165	60	22,04	2	R	Paraplegia (T12-T6)	20	24
10	Female	WH2	22	135	43	23,59	6	R	Osteogenesis imperfecta	18	24
11	Male	WH2	38	185	63	18,41	2	R	Paraplegia (T5-T6)	20	25
12	Male	WH2	44	165	58	21,30	9	R	Paraplegia (T12-L2/L3)	18	25
13	Male	WH1	40	187	70	20,02	5	R	Paraplegia (T5-T6)	20	25
14	Male	WH1	49	185	94	27,47	5	R	Paraplegia (T3-T4)	20	25
15	Male	WH1	52	160	60	23,44	3	L	Poliomieltitis	20	25
16	Female	WH2	41	175	68	22,20	9	R	Incomplete paraplegia (L1-L2)	18	25
17	Female	WH2	37	170	60	20,76	3	R	Incomplète paraplegia (T12-L1)	20	25
18	Female	WH2	27	156	47	19,31	4	R	Algoneurodystrophy	20	25
19	Male	WH1	33	178	100	31,50	14	R	Paraplegia (T6)	20	25
		Parameters							Description		
Mean			40.8	169.9	65.6	38.4	7.3				
(SD)			(8.8)	(12.7)	(13.4)	(6.0)	(4.0)				
					Propulsion technique parameters						

107 **Table 1:** Participants' characteristics.

108 *SD: standard deviation; BMI: Body Mass Index.*

109

110 *Data measurement*

111 Inertial measurement units (IMUs) were used to collect on-field data (11,20–22). Their
 112 wheelchair was equipped bilaterally with two IMUs (128 Hz, 3*3: accelerometer, gyroscope,
 113 magnetometer, and Bluetooth module, WheelPerf System, AtoutNovation, France). IMUs
 114 were placed on each wheel hub, and the gyroscope was used to estimate the direct rotational
 115 velocity of the wheel around the z-axis, considering the camber angle of the wheelchair as
 116 indicated by Fuss et al. (23). The z-axes of gyroscopes were placed perpendicularly to the
 117 wheel planes (24). The data were filtered using a Butterworth low-pass filter of order 2 with a
 118 cutoff frequency of 4 Hz.

119 Data were processed using Python 3.11 and Kinetics Toolkit 0.11 (25). Figure 1 shows
 120 an example of propulsion velocity curve for one sprint in forward and backward propulsion.
 121 The various phases visible in Figure 1, such as acceleration, deceleration, or the transition
 122 phases, were manually marked using events and enabled us to calculate the outcome
 123 parameters. All the outcome parameters were calculated for all the 3 meters sprints performed
 124 by the athletes.

125 *Outcome Parameters*

126 To meet the objectives of this article, the same propulsion technique and performance
 127 parameters as in the study by Alberca et al. (12) were used and are listed in Table 2.

Propulsion phase time (PP_{mean}) [s]	Time between the sprint start and the first peak velocity
Deceleration phase time (DP_{mean}) [s]	Time between the last peak velocity and the sprint end
Performance parameters	
Sprint time (ST_{mean}) [s]	Sprint time of each direction of propulsion
Transition time (TT_{mean}) [s]	Time between the end of the deceleration phase and the start of the next sprint
Maximum velocity (V_{max}) [m/s]	Maximum velocities reached on all sprint
Mean velocity (V_{mean}) [m/s]	Mean velocities reached on all sprint
Peak velocity (V_{peak}) [m/s]	First maximum velocity reached during the sprint
Acceleration (A_{mean}) [m/s^2]	Mean acceleration between the sprint start and the first peak velocity
Deceleration (D_{mean}) [m/s^2]	Mean deceleration between the last peak velocity and the sprint end

128 **Table 2:** Description of the outcome measures.

129

130 In addition to the definitions shown in Table 2, Figure 2 illustrates the various parameters
131 calculated.

132

[Figure 2]

133 **Figure 2:** Example of propulsion velocity curve for one sprint in forward and backward
134 propulsion

135 The acceleration and propulsion phase time were calculated only on the beginning of
136 each sprint because it is the only moment when athletes accelerate the most from a stationary
137 position since the wheelchair is stopped and has no velocity. The same reasoning is applied to
138 the deceleration phase time and deceleration. These parameters are only calculated in the end
139 of the sprint since it is the only moment when athletes brake to stop the wheelchair and
140 completely decelerate (12).

141 **Statistical methods**

142 To meet the main objective of our study, the first step is to compare the data of WH1
143 and WH2 athletes in forward propulsion and in backward propulsion. To do this, the averaged
144 IMU data for the left and right wheel were used, in forward and backward propulsion, for
145 WH1 and WH2 athletes. Normality of the data was tested using a Shapiro-Wilk test, which
146 showed that the data were not normally distributed. Therefore, non-parametric independent
147 Mann-Whitney tests has been chosen for the comparisons. Significance was set at $p < 0.05$.

148 For each significant difference, the effect size r was calculated using the following
149 equation:

150
$$r = \frac{Z}{\sqrt{N}}$$

151 *With Z: statistical result of the statistical test for the parameter under consideration; N:*
152 *sample size.*

153 Effect size was interpreted according to (26): small ($d = 0.1$), moderate ($d = 0.3$), and
154 large ($d = 0.5$).

155 After this initial analysis, the main objective is to explore the possibility that the
156 temporal and kinematic data from this study could serve as evidence for the evidence-based

157 classification of wheelchair badminton athletes. To this end, a principal component analysis
158 (PCA) was performed on parameters showing a significant difference between WH1 and
159 WH2 according to the previous statistical analysis. Propulsion technique parameters and
160 performance parameters with no significant differences between WH1 and WH2 were not
161 considered in the analysis. Then, hierarchical clustering was performed on the coordinates
162 obtained through PCA to identify similarities across classifications. This clustering method is
163 based on iteratively merging data into larger clusters based on their Euclidean distance. In this
164 hierarchical clustering analysis, it is interesting to examine whether the clusters exhibit
165 significant differences among them and to identify on which principal component these
166 differences manifest between the clusters to enhance the understanding of the clusters. To test
167 the hypothesis of a difference between clusters on each PCA component, two non-parametric
168 Kruskal-Wallis tests were performed, as the normality hypothesis was rejected by the
169 Shapiro-Wilk test. Then, pairwise comparisons of clusters on each PCA component were
170 conducted using the Mann-Whitney post-hoc test with Bonferroni correction. Lastly, to
171 understand the distribution of PC classifications within the clusters, a contingency table was
172 created. Results are reported in percentage (%).

173 **Results**

174 *Impact of classification on performance*

175 The results of the comparison of data between WH1 and WH2 athletes are presented
176 in Table 3 (a) for forward propulsion and Table 3 (b) for backward propulsion and, in Figure
177 3.

178 **Table 3:** Comparison of propulsion technique and performance parameters between the two
 179 classes (WH1 and
 180 WH2) for the forward
 181 propulsion (a) and the
 182 backward propulsion
 183 (b).

Forward	WH1	WH2	Comparison	
	Mean(SD)	Mean(SD)	<i>p</i>	<i>r</i>
Propulsion technique parameters				
PP _{mean} (s)	0.47(±0.17)	0.44(±0.18)	0.376	0.076
DP _{mean} (s)	0.45(±0.17)	0.37(±0.11)	0.002*	0.263
Performance parameters				
ST _{mean} (s)	2.19(±0.78)	1.98(±0.29)	<0.001	0.414
TT _{mean} ¹ (s)	0.39(±0.23)	0.41(±0.28)	0.806	0.021
V _{max} (m/s)	4.31(±0.70)	4.71(±0.59)	<0.001*	0.332
V _{mean} (m/s)	2.94(±0.53)	3.05(±0.42)	0.079	0.158
V _{peak} (m/s)	2.98(±0.94)	3.15(±0.89)	0.015*	0.208
A _{mean} (m/s ²)	5.36(±1.76)	6.08(±1.65)	<0.001*	0.300
D _{mean} (m/s ²)	8.46(±3.56)	11.77(±3.80)	<0.001*	0.439

191

192

Backward	WH1	WH2	Comparison	
	Mean(SD)	Mean(SD)	<i>p</i>	<i>r</i>
Propulsion technique parameters				
PP _{mean} (s)	0.43(±0.15)	0.43(±0.15)	0.483	0.060
DP _{mean} (s)	0.43(±0.15)	0.35(±0.11)	<0.001*	0.323
Performance parameters				
ST _{mean} (s)	2.42(±0.63)	2.27(±0.75)	<0.001	0.453
TT _{mean} ² (s)	0.43(±0.25)	0.41(±0.28)	<0.001	0.344
V _{max} (m/s)	3.84(±0.67)	4.17(±0.54)	<0.001*	0.347
V _{mean} (m/s)	2.64(±0.36)	2.83(±0.31)	<0.001*	0.321
V _{peak} (m/s)	2.66(±0.51)	3.05(±0.81)	<0.001*	0.292
A _{mean} (m/s ²)	5.98(±1.63)	6.26(±1.55)	0.126	0.131
D _{mean} (m/s ²)	7.61(±2.63)	11.09(±3.46)	<0.001*	0.589

203

204 *SD: standard deviation; p: p-value fixed at 0.05; r: effect size for the significant difference;*
 205 *Bold values indicate significant values; ¹: transition time from forward propulsion to*
 206 *backward propulsion; ²: transition time from backward propulsion to forward propulsion;*
 207 *PP_{mean}: propulsion phase time on the first push; DP_{mean}: deceleration phase time on the last*
 208 *push; ST_{mean}: sprint time; TT_{mean}: transition time; V_{max}: maximum velocity; V_{mean}: mean*
 209 *velocity; V_{peak}: peak velocity on the first push; A_{mean}: acceleration on the first push; D_{mean}:*
 210 *deceleration on the last push.*

211 Regarding forward propulsion, WH1 athletes demonstrate slightly to moderately
 212 higher values for ST_{mean} and DP_{mean} compared to athletes in the WH2 class. Conversely, WH1
 213 athletes exhibit slightly to moderately lower values for V_{max}, V_{peak}, A_{mean}, and D_{mean} in

214 comparison to WH2 athletes. No significant difference was found regarding PP_{mean} , TT_{mean}
 215 and V_{mean} between WH1 and WH2 athletes.

216 About backward propulsion, like forward propulsion, WH1 athletes exhibit
 217 significantly moderately higher values for DP_{mean} , ST_{mean} and TT_{mean} compared to WH2
 218 athletes. Conversely, WH1 athletes show significantly lower values for V_{max} , V_{mean} , V_{peak} , and
 219 D_{mean} compared to WH2 athletes. No significant difference was found regarding PP_{mean} and
 220 A_{mean} between WH1 and WH2 athletes.

221 In the initial analysis, significant differences in velocity were observed between WH1
 222 and WH2 athletes. Given TT_{mean} 's representation of 13 to 21% of the total sprint duration and
 223 is influenced by athletes' velocities, it was decided to exclude this parameter from the
 224 performance metrics considered for hierarchical clustering.

225 *Principal component analysis and hierarchical clustering*

226 The PCA revealed two principal components explaining together 64.35% of the overall
 227 variance. The first component (PC1) accounts for 54.30% of the variance and is linked to
 228 velocity parameters as indicated in Table 4. The second component (PC2) explains 10.05% of
 229 the variance and is related to temporal and propulsion technique parameters.

230 **Table 4:** Results of the principal component analysis and coordinate of each variable in each
 231 PCA components as well as percentage of variance.

	Principal component 1 (PC1)	Principal component 2 (PC2)
Variance (%)	54.30	12.05
Forward propulsion		
DP_{mean}	-0.557	0.703
ST_{mean}	-0.791	0.468
V_{max}	0.850	0.293
V_{peak}	0.599	0.003
A_{mean}	0.727	-0.047
D_{mean}	0.772	-0.466
Backward propulsion		
DP_{mean}	-0.376	-0.242
ST_{mean}	-0.854	0.043
V_{max}	0.870	0.309
V_{mean}	0.822	0.436
V_{peak}	0.693	0.002
D_{mean}	0.768	0.288

232

233 Three distinct clusters were identified through hierarchical clustering analysis on PCA
 234 components. The three clusters are represented in Figure 3.

235 **[Figure 3]**

236 **Figure 3:** Clustering analysis in each variable on each PCA component.

237 *With colored polygons: each cluster, colored dot: observations of each athlete in dark red for*
238 *WH1 and blue for WH2*

239 Regarding PC1, significant differences were noted across all clusters ($p < 0.001$).
240 Regarding PC2, significant differences were noted for the cluster 1 ($p < 0.001$) and cluster 3
241 ($p = 0.002$). But no significant difference was observed for cluster 2 meaning that PC2
242 contribute contributes slightly less to the distinction between clusters than the PC1. These
243 significant differences make it possible to validate the discrimination of the clusters on the
244 principal components identified. The percentage distribution of classifications by cluster is
245 available in Table 5.

246 **Table 5:** Contingency table representing the percentages of WH1 and WH2 in each cluster (in
247 %).

	248	
	WH1	WH2
	249	
Cluster 1	82.50	17.50
Cluster 2	45.26	54.74
Cluster 3	52.56	47.44

252

253 Cluster 1 is predominantly composed of WH1 athletes at 82.50% compared to 17.50%
254 WH2. In contrast, the distributions of clusters 2 and 3 are much more balanced, with 45.26%
255 WH1 and 54.74% WH2 for cluster 2, and 52.56% WH1 and 47.44% WH2 in cluster 3.

256 **Discussion**

257 To our knowledge, the analysis presented in this article represents the first exploration
258 within the realm of wheelchair badminton. Its main objective of this study was to explore the
259 utility of the temporal and kinematic data link to propulsion technique and athlete
260 performance to contribute evidence-based classification in wheelchair badminton. Differences
261 in the parameters measured were observed between the two classifications in a way that
262 indicates a longer braking time for WH1 compared to WH2, as well as overall lower
263 performance in terms of sprint times and velocity parameters. Contrary to our initial
264 hypothesis, hierarchical clustering analysis did not align with current classifications, revealing
265 three distinct clusters instead of two. This method is an attempt to allow the current
266 classification system to evolve towards an evidence-based classification, by including
267 objective scientific measurements of the performance of the athletes considered and their
268 propulsion technique. Future research is needed to implement this method and its database.

269 **Comparison of data between WH1 and WH2 athletes.**

270 Regarding propulsion technique parameters, WH2 athletes exhibit a lower deceleration
271 phase compared to those WH1, regardless of the direction of propulsion considered. This is in
272 line with the initial hypothesis. However, the propulsion phase shows no significant
273 differences between the two classes for both propulsion directions. It appears that athletes
274 classified WH2 modify their propulsion technique by reducing braking phases. This
275 observation could be attributed to the superior abdominal capabilities of WH2 athletes,
276 allowing them to lean further forward or backward on the wheelchair compared to WH1
277 athletes, thereby enabling more effective braking. Indeed, a recent study of Garner & Ricard
278 (27), had shown that athletes with lower trunk functional capacity exhibited higher angular
279 impulse and trunk extension angles during braking (27). In addition to the challenges related

280 to trunk mobility, individuals without abdominal strength need to stabilize themselves with
281 one hand during braking phases to avoid tipping forward or backward. This prevents them
282 from fully braking with both hands.

283 In forward propulsion, WH1 athletes exhibit longer sprint times, lower maximum and
284 peak velocities, and reduced acceleration and deceleration compared to WH2 athletes. Similar
285 results are observed in backward propulsion, except for acceleration, where no significant
286 difference is found between the WH1 and WH2 groups. Also, the transition time for WH1
287 athletes is greater than for WH2 in backward propulsion, while their velocities are decreasing.
288 These results confirm the initial hypothesis and can be attributed to functional abilities,
289 particularly abdominal strength, which plays a crucial role in trunk mobility. Indeed, trunk
290 movements and stability directly influence the functional performance of athletes, as they are
291 essential mechanisms for generating propulsion force (28–30). Moreover, a more severe
292 impairment leads to decreased postural stability and propulsion capabilities (15). Thus, WH1
293 athletes, who have greater impairment of the trunk and abdominal muscles, experience more
294 pronounced negative effects on their wheelchair propulsion performance compared to WH2
295 athletes.

296 Research on wheelchair sports performance among reveals significant differences based
297 on athlete classification, particularly in sports like rugby and basketball (16,17,31–33).
298 Higher-classified athletes tend to have better aerobic and anaerobic capacity, upper limb
299 strength, and sport-specific skills, with parameters like oxygen consumption, sprint velocity,
300 and game efficiency favoring high-point players (34,35). Additionally, higher-classified
301 athletes generally show better shoulder strength, aerobic, and anaerobic capacity, underlining
302 the importance of both biomechanical and physiological factors in training (33). These results
303 are consistent with ours and highlight the importance of using such parameters in the athlete
304 classification process.

305 *Hierarchical clustering analysis*

306 Cluster analysis on the principal components of the PCA revealed three clusters,
307 contrary to the initial hypothesis of two expected clusters. According to the Mann-Whitney
308 post-hoc test, only PC1 contributes significantly to distinguishing between clusters. PC1
309 primarily represents velocity data of athletes, which appears to be the most discriminative
310 factor in classifying athletes into three clusters. This finding suggests that the data from this
311 study do not adequately classify athletes according to the two existing classes of wheelchair
312 badminton. However, while the cluster analysis did not reveal two clusters, it revealed three.
313 The distribution of athletes across the different clusters varies. In particular, the first cluster is
314 predominantly composed of WH1 athletes (65.75%), while clusters 2 and 3 have much more
315 balanced distributions between WH1 and WH2. To understand this distribution, the number
316 of years of practice was studied as an explanatory factor. Athletes are classified as “less
317 experienced” if they have less than 5 years of practice, as “experienced” if they have between
318 5 and less than 10 years of experience, and as “very experienced” if they have 10 years or
319 more of practice. Following this grouping, the proportions were determined in each cluster
320 (see Table 6).

321 **Table 6:** Contingency table representing the percentages of beginners, intermediates and
322 advanced in each cluster (in %).

	Less experienced	Experienced	Very experienced
Cluster 1	57.53	42.47	0.00
Cluster 2	46.97	50.00	3.03

Cluster 3	4.05	59.46	36.49
-----------	------	-------	-------

324

325

326

327 Based on the findings from Table 6, it is evident that cluster 1 predominantly consists of
 328 athletes labeled as "less experienced" (57.53%), while cluster 3 almost exclusively comprises
 329 "highly experienced" athletes. Additionally, cluster 2 presents a blend of athletes classified as
 330 "less experienced" (46.97%) and "experienced" (50.00%). Consequently, years of experience
 331 emerge as a possible explanatory factor for the observed cluster patterns and the distribution
 332 of WH1 and WH2 athletes. These findings suggest that years of experience may exert an
 333 influence on athletes' performance and their propulsion technique.

334 Recent studies have explored the use of clustering methods, like in this article, for
 335 classification in wheelchair sports. Marszałek et al. (36) found significant correlations
 336 between functional classes and anaerobic power, suggesting a valid division of wheelchair
 337 basketball players into four different classes. Van der Slikke et al. (37) used inertial sensors to
 338 measure wheelchair mobility performance, revealing only two performance-based clusters in
 339 wheelchair basketball, suggesting a potential reduction in classification groups. Connick et al.
 340 (9) employed cluster analysis of isometric strength tests for wheelchair racing, producing four
 341 clusters that better reflected activity limitations compared to the current classification system.
 342 These studies and the results of this article highlight the potential of data-driven clustering
 343 approaches to enhance classification systems and inform coaching strategies in wheelchair
 344 sports.

345 However, the results of this study need to be interpreted with caution. Indeed, in this
 346 article, performance parameters were selected with propulsion technique parameters for
 347 clustering analysis due to their rapid measurement and ease of acquisition. However, it is
 348 important to acknowledge that an athlete's performance can vary for various reasons, both
 349 intrinsic and extrinsic. Taking these considerations into account, along with the results
 350 obtained in this study, which did not allow for the identification of the current classification,
 351 the decision to use performance parameters in the clustering analysis raises questions. Thus,
 352 the results of this article point more to the need to improve the current methodology
 353 employed, than to a revision of the current classification. One conceivable approach would be
 354 to incorporate functional parameters, such as trunk or upper limb mobility. In wheelchair
 355 basketball, for example, functional classification assesses the trunk and upper limb capacities
 356 of players, reflecting their ability to perform various actions on the court. The validity of this
 357 approach has been demonstrated in various fields, including physiology, biomechanics, and
 358 game performance (2,38,39). Integrating similar objective biomechanical measures could
 359 strengthen the clustering methodology of this study and lead to a more precise classification
 360 based on tangible data. This evolution could enhance the classification process of wheelchair
 361 badminton players, or even prompt its revision if the results justify it. Moreover, such an
 362 approach would refine and scientifically reinforce the classification, bringing it closer to the
 363 concept of evidence-based classification.

364 ***Limitations***

365 The primary limitation of this study is the absence of kinetic data. Including such data
 366 could have provided a more comprehensive assessment of athlete performance and further
 367 validated the established clusters. Future research could address this by incorporating
 368 additional kinetic measurements to enhance the robustness of the findings.

369 Furthermore, the instruction given to athletes during the tests was to align the large
370 wheelchair wheel with the start/finish lines to validate the sprint. Despite the particular
371 attention paid to adhering to this instruction, it is possible that athletes did not consistently
372 comply with it throughout the entire 1-minute test duration. Considering this, it is conceivable
373 that the distance covered by each athlete may vary, potentially influencing the velocity results.
374 An improvement could involve employing photoelectric cells at the start and finish lines,
375 signaled by an audible tone upon passage. Athletes would then be instructed to trigger the cell
376 at the end of each sprint.

377

378

379 *Perspectives*

380 Regarding the characterization of WH1 and WH2 athletes, the results obtained in this
381 article could serve as a performance database for coaches and athletes. Indeed, this could
382 enable them to assess their position relative to a global average level, with the potential for
383 individualization and strategic direction in athlete training.

384 A concrete perspective for the clustering results presented in this article would be to
385 propose to the BWF to integrate more tests based on the evaluation of athletes' functional
386 capacities and objective biomechanical measurements into the existing classification process.
387 Indeed, with the aim of objectifying the classification process using rapid tests and non-
388 invasive measurements, the current classification could become more representative of
389 athletes' abilities, based on the concept of evidence-based classification. In addition to
390 velocity measurements, it would be interesting to add the evaluation of the volume of action
391 of athletes with measurements of trunk kinematics to the classification process.

392 **Conclusion**

393 To conclude, this article highlights the following points:

- 394 - WH1 athletes have a longer braking phase than WH2 athletes.
- 395 - Overall, WH1 athletes perform less well than WH2 athletes regardless of the
396 direction of propulsion.
- 397 - The temporal and kinematic data in this study did not allow for the identification of
398 the current classification, as three clusters emerged instead of two.

399 Thus, the results of this study could suggest a potential evolution of the current
400 classification towards three distinct classes of wheelchair badminton players. However, these
401 findings should be interpreted with caution, given that the included performance parameters
402 can be influenced by numerous factors, potentially undermining the robustness of the
403 clustering methodology employed.

404 This study highlights the need to strengthen the current classification process in
405 wheelchair badminton. To align with IPC guidelines and enhance the methodology employed
406 in this study, integrating functional trunk capacity data could prove to be beneficial.

407 **Financial disclosure**

408 The authors declare no conflict of interest. This work was supported by a French
409 government grant, managed by the Agence Nationale de la Recherche (ANR) under the
410 "France 2030" program, reference ANR-19-STHP-0005. The funders had no role in study
411 design, data collection and analysis, decision to publish, or preparation of the manuscript.

412 **Acknowledgments**

413 The authors thank the participants in the study as well as the laboratory of the J-AP2S
414 and the Fédération Française de Badminton.

415 **References**

416 1. Mann DL, Tweedy SM, Jackson RC, Vanlandewijck YC. Classifying the
417 evidence for evidence-based classification in Paralympic sport. *Journal of Sports Sciences*.
418 2021;39(sup1):1–6.

419 2. Goosey-Tolfrey VL, Leicht CA. Field-Based Physiological Testing of
420 Wheelchair Athletes. *Sports Med*. 2013;43(2):77–91.

421 3. BWF. BWF Statutes, Section 5.5.5: PARA BADMINTON
422 CLASSIFICATION REGULATIONS. BWF. [Internet]. 2020. Available from:
423 [https://extranet.bwfbadminton.com/docs/document-](https://extranet.bwfbadminton.com/docs/document-system/81/1466/1471/Section%205.5.5%20-%20Para%20Badminton%20Classification%20Regulations.pdf)
424 [system/81/1466/1471/Section%205.5.5%20-](https://extranet.bwfbadminton.com/docs/document-system/81/1466/1471/Section%205.5.5%20-%20Para%20Badminton%20Classification%20Regulations.pdf)
425 [%20Para%20Badminton%20Classification%20Regulations.pdf](https://extranet.bwfbadminton.com/docs/document-system/81/1466/1471/Section%205.5.5%20-%20Para%20Badminton%20Classification%20Regulations.pdf)

426 4. Janiaczyk M. Para-badminton – sport for people with disabilities.
427 *Physiotherapy*. 2015;23(4).

428 5. Clarkson HM. *Musculoskeletal Assessment: Joint Range of Motion and*
429 *Manual Muscle Strength*. 2nd ed. 2000. (Lippincott Williams & Wilkins).

430 12. Maynard FM, Bracken MB, Creasey G, Ditunno JF, Donovan WH, Ducker B,
431 et al. International Standards for Neurological and Functional Classification of Spinal Cord
432 Injury. *Spinal Cord*. 1997;35:266-274.

433 13. Tweedy SM, Vanlandewijck YC. International Paralympic Committee position
434 stand--background and scientific principles of classification in Paralympic sport. *British*
435 *Journal of Sports Medicine*. 2011;45(4):259–69.

436 8. Van Der Slikke RMA, Bregman DJJ, Berger MAM, De Witte AMH, Veeger
437 DJ (H.) EJ. The Future of Classification in Wheelchair Sports: Can Data Science and
438 Technological Advancement Offer an Alternative Point of View? *International Journal of*
439 *Sports Physiology and Performance*. 2018 Jul 1;13(6):742–9.

440 9. Connick MJ, Beckman E, Vanlandewijck Y, Malone LA, Blomqvist S,
441 Tweedy SM. Cluster analysis of novel isometric strength measures produces a valid and
442 evidence-based classification structure for wheelchair track racing. *Br J Sports Med*. 2018
443 Sep;52(17):1123–9.

444 10. Altmann VC, Groen BE, Hart AL, Vanlandewijck YC, Keijsers NLW.
445 Classifying trunk strength impairment according to the activity limitation caused in
446 wheelchair rugby performance. *Scandinavian Med Sci Sports*. 2018 Feb;28(2):649–57.

447 14. Bakatchina S, Weissland T, Faupin A. Les dispositifs d'évaluation des
448 parasportifs pratiquant des sports de petits terrains en fauteuil roulant manuel. *Mov Sport*
449 *Sci/Sci Mot*. 2021;4(114):55–69.

450 12. Alberca I, Chénier F, Watier B, Brassart F, Vallier JM, Faupin A. Impact of
451 holding a badminton racket on temporal and kinematic parameters during manual wheelchair
452 propulsion based on forward and backward propulsion. [Internet]. HAL; 2024. Available
453 from: <https://hal.science/hal-04594677>

- 454 5. Bolin I, Bodin P, Kreuter M. Sitting position–Posture and performance in C5–
455 C6 tetraplegia. *Spinal Cord*. 2000;38(7):425–34.
- 456 7. Seelen HAM, Potten YJM, Drukker J, Reulen JPH, Pons C. Development of
457 new muscle synergies in postural control in spinal cord injured subjects. *Journal of*
458 *Electromyography and Kinesiology*. 1998;8(1):23–34.
- 459 6. Gagnon D, Verrier M, Masani K, Nadeau S, Aissaoui R, Popovic M. Effects of
460 Trunk Impairments on Manual Wheelchair Propulsion Among Individuals with a Spinal Cord
461 Injury: A Brief Overview and Future Challenges. *Topics in Spinal Cord Injury Rehabilitation*.
462 2009;15(2):59–70.
- 463 16. Mota Ribeiro, de Almeida. Performance analysis in wheelchair para-badminton
464 matches. *International Journal of Racket Sports Science*. 2020;2(1):22–31.
- 465 9. Strapasson AM. Are Technical and Timing Components in Para-Badminton
466 Classifications Different? *Int. j. racket sports sci*. 2021;3(1):22-27.
- 467 10. Strapasson AM, Chiminazzo JGC, de Almeida MB, Duarte E. Para-badminton:
468 technical and temporal characteristics. *Physical Education and Sport Journal*. 2018;16(2):57-
469 63.
- 470 16. Rhodes JM, Mason BS, Malone LA, Goosey-Tolfrey VL. Effect of team rank
471 and player classification on activity profiles of elite wheelchair rugby players. *Journal of*
472 *Sports Sciences*. 2015;33(19):2070–8.
- 473 17. Mason BS, Lenton JP, Goosey-Tolfrey VL. The physiological and
474 biomechanical effects of forwards and reverse sports wheelchair propulsion. *The Journal of*
475 *Spinal Cord Medicine*. 2015;38(4):476–84.
- 476 18. van der Slikke RMA, Berger M a. M, Bregman DJJ, Lagerberg AH, Veeger
477 HEJ. Opportunities for measuring wheelchair kinematics in match settings; reliability of a
478 three inertial sensor configuration. *J Biomech*. 2015;48(12):3398–405.
- 479 19. Xu H, Chua JC, Burton M, Zhang K, Fuss FK, Subic A. Development of low
480 cost on-board velocity and position measurement system for wheelchair sports. *Procedia*
481 *Engineering*. 2010;2(2):3121–6.
- 482 20. Fuss FK. Speed measurements in wheelchair sports – theory and application.
483 *Sports Technology*. 2012;5(1–2):29–42.
- 484 21. Poulet Y, Brassart F, Simonetti E, Pillet H, Faupin A, Sauret C. Analyzing
485 Intra-Cycle Velocity Profile and Trunk Inclination during Wheelchair Racing Propulsion.
486 *Sensors*. 2022;23(1):58.
- 487 22. Chénier F. Kinetics Toolkit: An Open-Source Python Package to Facilitate
488 Research in Biomechanics. *JOSS*. 2021;6(66):3714.
- 489 26. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed.
490 Hillsdale, N.J: L. Erlbaum Associates; 1988. 567 p.
- 491 27. Garner TD, Ricard MD. Effects of Trunk Functional Capacity on the Control
492 of Angular Momentum During Manual Wheelchair Braking. *TOSSJ*. 2022 Nov
493 1;15(1):e1875399X2208150.
- 494 28. Vanlandewijck YC, Verellen J, Tweedy S. Towards evidence-based
495 classification in wheelchair sports: Impact of seating position on wheelchair acceleration.

- 496 Journal of Sports Sciences. 2011 Jul;29(10):1089–96.
- 497 29. Vanlandewijck Y, Theisen D, Daly D. Wheelchair propulsion biomechanics:
498 implications for wheelchair sports. *Sports Med.* 2001;31(5):339–67.
- 499 30. Gil-Agudo A, Del Ama-Espinosa A, Crespo-Ruiz B. Wheelchair Basketball
500 Quantification. *Physical Medicine and Rehabilitation Clinics of North America.* 2010
501 Feb;21(1):141–56.
- 502 31. Bakatchina S, Weissland T, Astier M, Pradon D, Faupin A. Performance,
503 asymmetry and biomechanical parameters in wheelchair rugby players. *Sports Biomechanics.*
504 2021 Apr 1;1–14.
- 505 32. Morgulec-Adamowicz N, Kosmol A, Molik B, Yilla AB, Laskin JJ. Aerobic,
506 Anaerobic, and Skill Performance With Regard to Classification in Wheelchair Rugby
507 Athletes. *Research Quarterly for Exercise and Sport.* 2011 Mar;82(1):61–9.
- 508 33. Soylu Ç, Yıldırım NÜ, Akalan C, Akınoğlu B, Kocahan T. The Relationship
509 Between Athletic Performance and Physiological Characteristics in Wheelchair Basketball
510 Athletes. *Research Quarterly for Exercise and Sport.* 2021 Oct 2;92(4):639–50.
- 511 34. Simim MAM, De Mello MT, Silva BVC, Rodrigues DF, Rosa JPP, Couto BP,
512 et al. Load Monitoring Variables in Training and Competition Situations: A Systematic
513 Review Applied to Wheelchair Sports. *Adapted Physical Activity Quarterly.* 2017 Oct
514 1;34(4):466–83.
- 515 35. Marcolin G, Petrone N, Benazzato M, Bettella F, Gottardi A, Salmaso L, et al.
516 Personalized Tests in Paralympic Athletes: Aerobic and Anaerobic Performance Profile of
517 Elite Wheelchair Rugby Players. *JPM.* 2020 Sep 9;10(3):118.
- 518 36. Marszałek J, Kosmol A, Morgulec-Adamowicz N, Mróz A, Gryko K, Klavina
519 A, et al. Anaerobic Variables as Specific Determinants of Functional Classification in
520 Wheelchair Basketball. *Journal of Human Kinetics.* 2022 Apr 26;82:243–52.
- 521 37. Van Der Slikke RMA, Mason BS, Berger MAM, Goosey-Tolfrey VL. Speed
522 profiles in wheelchair court sports; comparison of two methods for measuring wheelchair
523 mobility performance. *Journal of Biomechanics.* 2017 Dec;65:221–5.
- 524