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Impact of holding a badminton racket on temporal and kinematic parameters during manual wheelchair propulsion based on forward and backward propulsion.

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Abstract:

Introduction: This study evaluates the impact of a badminton racket on forward and backward propulsion in wheelchair badminton, aiming to discern if this impact varies between propulsion directions. **Materials and Methods:** Nineteen experienced wheelchair badminton players underwent propulsion tests with and without a badminton racket. **Results:** In forward propulsion, the badminton racket distinctly alters propulsion technique parameters depending on the propulsion direction. It increases sprint time by 4% to 5% and reduces mean, maximum, and peak velocities by 3% to 8% regardless of propulsion direction. Deceleration is also diminished by 9% to 11% with the racket in both directions, potentially decreasing overall performance. Notably, while the impact of the racket differs between propulsion directions, there is no significant difference in the effect between forward and backward propulsion. **Conclusion:** The use of a badminton racket influences propulsion technique parameters differently based on the propulsion direction and affects performance parameters such as velocity and deceleration consistently across both directions. However, the direction of propulsion does not amplify the racket's effect. These findings underscore the importance for wheelchair badminton players and coaches to consider equipment effects on performance in both forward and backward propulsion.

Key words: adapted sport; biomechanics; performance; disability

Main text introduction

Wheelchair badminton gained significant attention after its inclusion in the 2021 Tokyo Paralympic Games. This racket sport has unique features, including using a badminton racket for propulsion and primarily forward and backward movements. Despite limited studies on the impact of using a badminton racket on propulsion, recent research addressed this question (Alberca et al., 2022a; Fukui et al., 2020). Alberca et al. (2022a) found that using a badminton racket alters force application, reducing propulsion effectiveness. Fukui et al. (2020) reported fewer sprints and increased muscle hardness and deoxygenated hemoglobin levels with a badminton racket. In wheelchair tennis, which shares similar characteristics with wheelchair badminton, more studies (Alberca et al., 2022b; de Groot et al., 2017; Goosey-Tolfrey & Moss, 2005) explored racket impact on propulsion. They observed reduced velocity, adverse effects on technique, and decreased propulsive moment, potentially affecting overall performance. These findings suggest that using tennis or badminton rackets alters

athletes' kinetics and spatiotemporal parameters (Alberca et al., 2022a; Alberca et al., 2022b; de Groot et al., 2017; Fukui et al., 2020; Goosey-Tolfrey & Moss, 2005), potentially decreasing performance.

Besides holding a badminton racket, wheelchair badminton players move mainly through forward propulsion and backward propulsion. Several studies have compared these two propulsion directions (Haubert et al., 2020; Linden et al., 1993; Mason et al., 2015; Salvi et al., 1998). However, Linden et al. (1993) and Salvi et al. (1998) reported conflicting results: Salvi et al. (1998) observed increased physiological responses (oxygen uptake, pulmonary ventilation, heart rate and rating of perceived exertion) during backward propulsion, while Linden et al. (1993) indicated decreased physiological responses. However, although the results of these authors are contradictory, these two authors have clearly highlighted the existence of a difference between these two propulsion directions. More recent studies by Mason et al. (2015) and Haubert et al. (2020) investigated forward propulsion and backward propulsion from physiological and spatiotemporal perspectives, revealing that backward propulsion increases physiological demands in association with an inability to develop sufficient force and required spatiotemporal adaptations to maintain the velocity, and modifies the shoulder biomechanics in a way that reduce shoulder pain (Haubert et al., 2020; Linden et al., 1993; Mason et al., 2015; Salvi et al., 1998).

The utilization of the racket and the directions of propulsion (forward and backward) are two inseparable components of wheelchair badminton that demand thorough investigation due to their potential impact on athlete performance. While previous studies suggest that the racket negatively influences wheelchair propulsion performance, they were conducted under laboratory conditions or with non-disabled individuals or focused on a different sports discipline and disregarding the specific propulsion direction (Alberca et al., 2022a; Alberca et al., 2022b; de Groot et al., 2017; Fukui et al., 2020; Goosey-Tolfrey & Moss, 2005). To accurately assess the impact of badminton racket on athletes' performance, considering their propulsion technique, it is essential to analyze key performance parameters in conditions that closely resemble those encountered during a match. The utilization of inertial units holds significant promise, particularly in facilitating the assessment of athletes under field conditions. This approach allows the measurement of various spatiotemporal parameters associated with propulsion technique and performance. Moreover, having a precise understanding of the impact of the badminton racket may facilitate exploring and evaluating potential solutions to mitigate these effects and improve the athletes' performance. Based on the wheelchair tennis literature, new handrim designs have been tested to optimize hand-to-racket/handrim coupling (de Groot et al., 2018; Rietveld et al., 2022). Additionally, considering new coatings for the handrim may be beneficial. Koopman et al. (2016) demonstrated various gripping techniques for the handrim with the racket in wheelchair tennis, suggesting the potential to ascertain an optimal gripping technique for wheelchair badminton. However, the initial step is to analyze and quantify the racket's impact. Nevertheless, the racket's effect cannot be dissociated from the two main propulsion directions employed by athletes.

More specifically, the spatiotemporal parameters of this study can be distinguished into two distinct categories: parameters related to propulsion technique and those linked to performance. Based on the above-mentioned studies demonstrating alterations in propulsion kinetics and a decrease in performance among able-bodied participants when using tennis or badminton rackets (Alberca et al., 2022a; Alberca et al., 2022b; de Groot et al., 2017; Fukui et al., 2020; Goosey-Tolfrey & Moss, 2005), it is plausible to hypothesize (1) that the use of a badminton racket will induce modifications in propulsion technique parameters and a decrease in performance parameters. Consequently, this could lead to an overall reduction in athletes' performances. Considering the physiological demands associated with backward propulsion, the biomechanical and spatiotemporal adjustments it entails (Haubert et al., 2020; Mason et al., 2015; Salvi et al., 1998), along with the fact that it is not the preferred propulsion method in daily life, integrating a racket into the motion of backward propulsion may be more difficult compared to forward propulsion. Consequently, it is possible to hypothesize (2) that the badminton racket effect will be greater in backward propulsion compared to forward propulsion.

Materials & methods

Study design

The study focuses on comparing measured parameters with racket and without racket, in the two directions of propulsion (forward and backward). Warmed-up participants performed consecutive forward and backward sprints over 3 meters for 1 minute to carry out a test as close as possible to match conditions as shown in Figure 1.

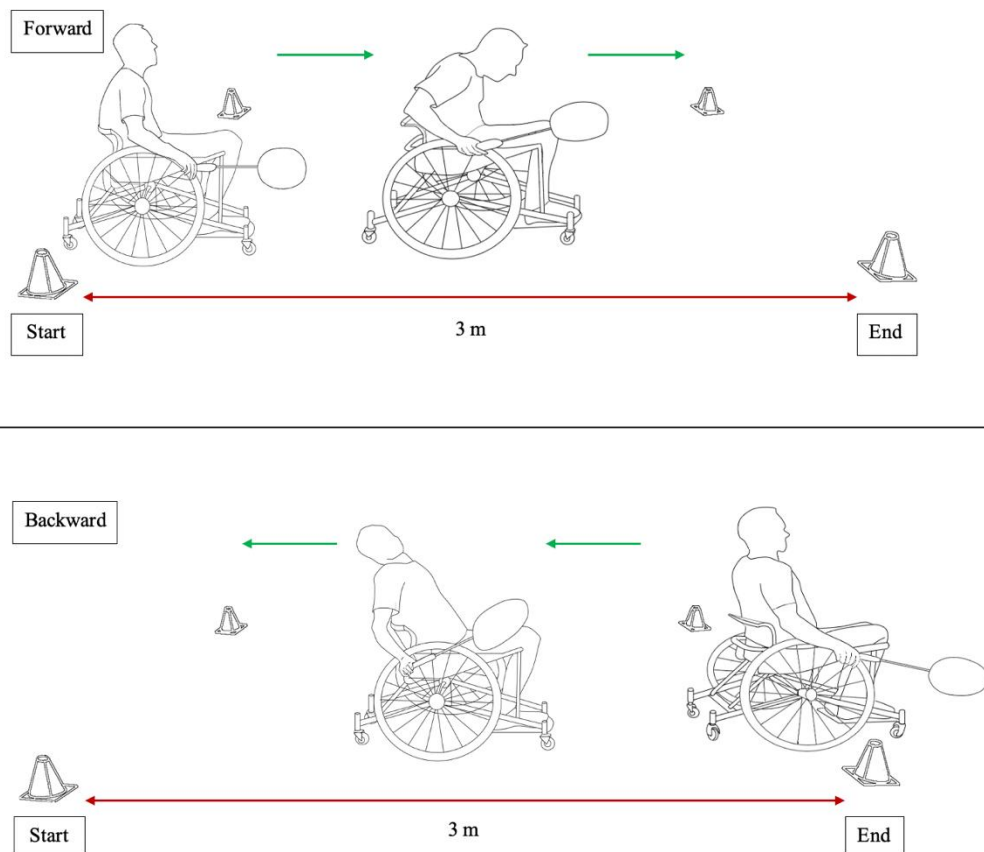


Figure 1: Schematic diagram of forward/backward propulsion test

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

Setting

The data of this study were collected during the French championships of Nueil-les-Aubiers from 14 to 16 January 2022 and Saint-Orens from 13 to 15 January 2023. The experimental protocol was approved by the Comité d'Éthique pour les Recherches en STAPS (CERSTAPS) from Conseil National des Universités de France [certificate #CERSTAPS **IRB00012476-2021-11-06-274**] filed on February 2021 and accepted on Jun 2021. Participants were recruited starting in December 2021. All participants signed a written consent form to take part in the study.

Participants

A total of 19 wheelchair badminton athletes was included in this study. Inclusion criteria required participants to be at a national level or higher in wheelchair badminton and have a minimum of one year of experience in playing the sport. Participants were excluded if they reported any pain or injury that could hinder their ability to propel their wheelchair. To determine the minimum sample size required for this study, a statistical power test has been made with de Groot et al. (2017) as the reference article. The required sample size

was estimated at N = 16 participants. Considering this result, a total of N = 19 badminton athletes was included in this analysis. Statistical power testing was performed using G*Power software (G*Power, 2020; g-power.apponic.com). Characteristics of all participants are presented in Table 1.

	Gender	Age (years)	Height (cm)	Body mass (kg)	BMI (kg/m ²)	Years of practice (years)	Racket side	Pathology	Camber (°)	Wheel size (inch)
1	Female	55	162	60	22,9	9	R	Paraplegia	20	24
2	Female	45	165	58	21,3	10	R	Paraplegia	18	25
3	Male	31	180	60	18,5	6	L	Paraplegia	18	26
4	Male	37	176	67	21,6	6	R	Paraplegia	20	25
5	Male	45	158	64	25,6	17	R	Spinabifida	18	25
6	Male	48	187	75	21,4	9	R	Paraplegia	20	26
7	Female	53	171	68	23,3	8	R	Paraplegia	20	25
8	Male	45	168	71	25,2	12	R	Paraplegia	20	25
9	Female	33	165	60	22,0	2	R	Paraplegia	20	24
10	Female	22	135	43	23,6	6	R	Osteogenesis imperfecta	18	24
11	Male	38	185	63	18,4	2	R	Paraplegia	20	25
12	Male	44	165	58	21,3	9	R	Paraplegia	18	25
13	Male	40	187	70	20,0	5	R	Paraplegia	20	25
14	Male	49	185	94	27,5	5	R	Paraplegia	20	25
15	Male	52	160	60	23,4	3	L	Polyomyelitis	20	25
16	Female	41	175	68	22,2	9	R	Incomplete paraplegia	18	25
17	Female	37	170	60	20,8	3	R	Incomplete paraplegia	20	25
18	Female	27	156	47	19,3	4	R	Algoneuro dystrophy	20	25
19	Male	33	178	100	31,6	14	R	Paraplegia	20	25
Mean(SD)		40.8(8.8)	169.9(12.7)	65.6(13.1)	22.6(3.2)	7.3(4.0)				

Table 1 Participants' characteristics

With SD: standard deviation; BMI: Body Mass Index.

Data processing

Inertial measurement units (IMUs) were used to collect on-field data (Bakatchina et al., 2021; Mason et al., 2015; van der Slikke et al., 2015; Xu et al., 2010). Their wheelchair was equipped bilaterally with two IMUs (128 Hz, 3*3: accelerometer, gyroscope, magnetometer, and Bluetooth module, WheelPerf System, AtoutNovation, France). IMUs were placed on each wheel hub, and the gyroscope was used to estimate the direct rotational velocity of the wheel around the z-axis, considering the camber angle of the wheelchair as indicated by Fuss et al. (2012). The z-axes of gyroscopes were placed perpendicularly to the wheel planes (Poulet et al., 2022). The data were filtered using a low-pass filter with a cutoff frequency of 4 Hz.

Data were processed using Python 3.11 and Kinetics Toolkit 0.11 (Chénier, 2021). Figure 1 shows an example of propulsion velocity curve for one sprint in forward and backward propulsion. The various phases visible in Figure 1, such as acceleration, deceleration, or the transition phases, were manually marked using events and enabled us to calculate the outcome parameters. All the outcome parameters were calculated for all the 3 meters sprints performed by the athletes.

Outcome Parameters

From the literature in wheelchair court sports, it is established that the ability to accelerate, sprint, brake, and move backwards has been identified as a key indicator of successful mobility and performance (Mason et al., 2013). Additionally, given the intrinsic nature of wheelchair badminton and observations made in the field, the ability to quickly achieve high velocity on the first push and the ability to brake and transition quickly to another direction of propulsion appear to be important for the athlete's performance. Since the objective of this study is to characterize the performance of wheelchair badminton athletes and this has not been done previously in the literature, the following parameters were included in this study following the previous observations:

- Peak velocity
- Acceleration
- Maximum and mean velocity
- Deceleration
- Transition time
- Sprint time

Two other parameters have also been integrated: the propulsion phase time and the deceleration phase time. These parameters hold significance as they contribute to the comprehension of both acceleration and deceleration processes, while also providing valuable insights into propulsion technique (Vanlandewijck et al., 2001). All the outcome parameters are presented and defined in Table 2 and grouped into two categories: propulsion technique parameters and performance parameters.

Parameters	Description
Propulsion technique parameters	
Propulsion phase time ($\mathbf{PP}_{\text{mean}}$) [s]	Time between the sprint start and the first peak velocity
Deceleration phase time ($\mathbf{DP}_{\text{mean}}$) [s]	Time between the last peak velocity and the sprint end
Performance parameters	
Sprint time ($\mathbf{ST}_{\text{mean}}$) [s]	Sprint time of each direction of propulsion
Transition time ($\mathbf{TT}_{\text{mean}}$) [s]	Time between the end of the deceleration phase and the start of the next sprint
Maximum velocity (\mathbf{V}_{max}) [m/s]	Maximum velocities reached on all sprint
Mean velocity (\mathbf{V}_{mean}) [m/s]	Mean velocities reached on all sprint
Peak velocity (\mathbf{V}_{peak}) [m/s]	First maximum velocity reached during the sprint
Acceleration (\mathbf{A}_{mean}) [m/s ²]	Mean acceleration between the sprint start and the first peak velocity

Table 2: Description of the outcome measures.

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

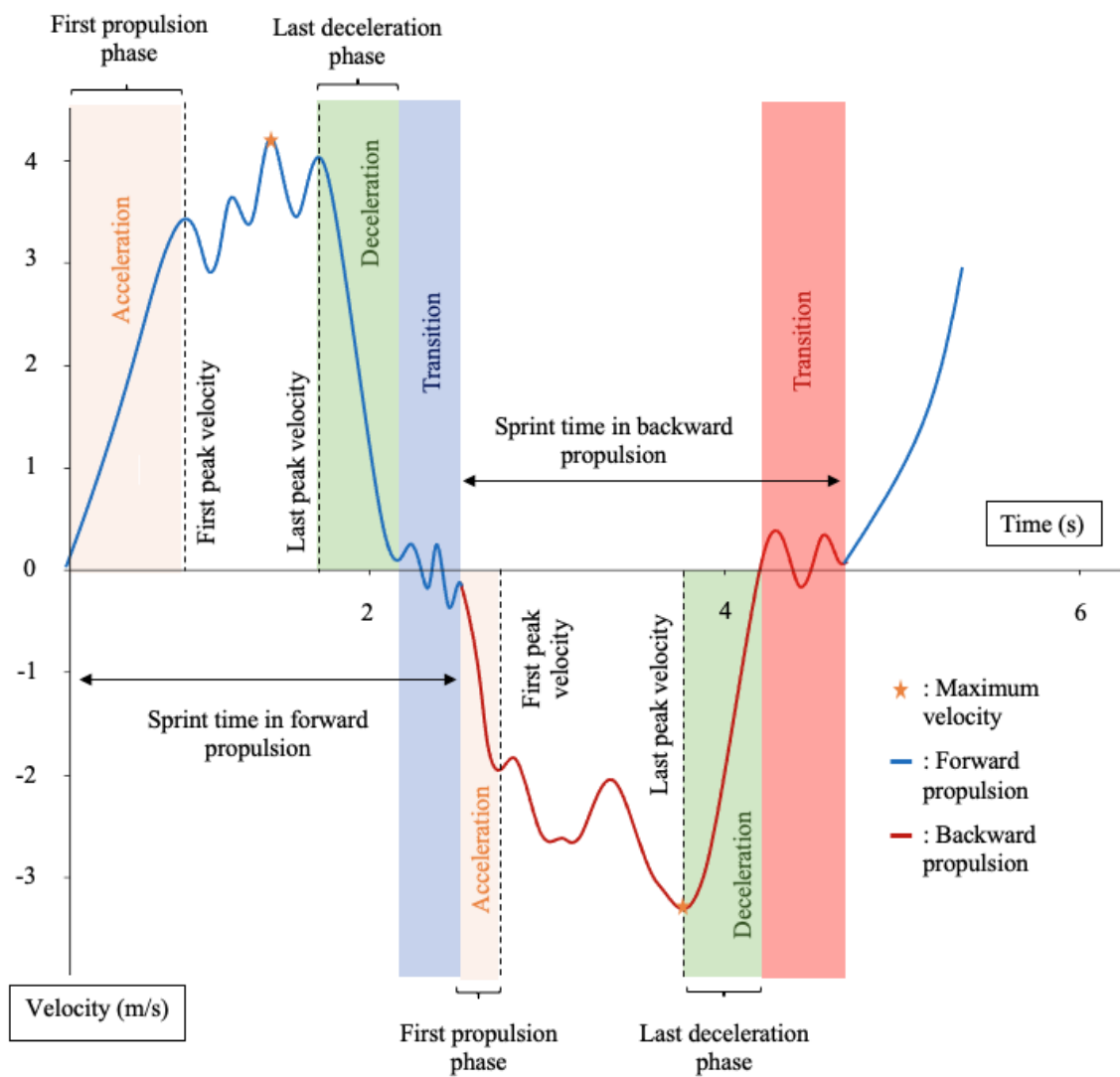


Figure 2: Example of propulsion velocity curve for one sprint in forward and backward propulsion

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

The transition time, time to switch from one direction propulsion to another, has been calculated for a transition from forward to backward propulsion, and from backward to forward propulsion. The distinction between the two is indicated in the results table. The transition phase has been excluded from the calculation of last deceleration because transitions correspond to the moment when the wheelchair wheel loses grip on the ground and skids, which does not accurately reflect the athlete's ability to decelerate or brake. This phase constitutes a separate aspect of the test.

In addition to those parameters, delta values (Δ) have been calculated to address the secondary objective of this investigation. The delta corresponds to the comparison between without racket and with racket data for the two propulsion directions using the following methodology:

$$\Delta x = x_{WOR} - x_{WR}$$

With x : parameter considered; WOR: without racket; WR: with racket.

Statistical methods

For all the nine parameters and delta values, mean of the data according to the test condition (without or with a racket) was calculated as well as their standard deviations in the two directions of propulsion. All data were analyzed using SPSS software version 20 (SPSS Inc., Chicago, Illinois USA).

Normality of the data was tested using a Shapiro-Wilk test, which showed that the data were not normally distributed. Therefore, a non-parametric Wilcoxon tests has been chosen for the comparisons. To accomplish the primary objective of this study, the initial analysis conducted involved comparing data obtained from the usual hand holding the racket, both with and without a badminton racket, during forward propulsion and backward propulsion. To accomplish the second objective, a comparative analysis of the deltas computed between forward propulsion and backward propulsion has been conducted. Significance was set at $p < 0.05$.

For each significant difference, the effect size d was calculated using the following equation in both propulsion directions:

$$d = \frac{\text{mean}(X_0) - \text{mean}(X_1)}{\text{s.d.}(X_0)}$$

With X : studied parameter, 0: data without racket according to the statistical analysis and 1: data with racket according to the statistical analysis.

Effect size was interpreted according to (Cohen, 1988): small ($d = 0.2$), moderate ($d = 0.5$), and large ($d = 0.8$).

Results

All participants completed the full experiment, and no data loss was observed.

Comparison of data with racket vs. without racket

The comparison of the data between the propulsion with and without a badminton racket are presented in Table 3.a for forward propulsion and Table 3.b for backward propulsion. In forward propulsion, a small increase in ST_{mean} , PP_{mean} , and DP_{mean} is observed in the condition with badminton racket compared to the condition without badminton racket. Conversely, V_{max} , V_{mean} , V_{peak} , A_{mean} and D_{mean} highlight small decrease when using the racket. In backward propulsion, TT_{mean} , PP_{mean} , V_{max} , V_{mean} , V_{peak} and D_{mean} all demonstrate small decrease in the condition with racket compared to the condition without racket while ST_{mean} slightly increases.

Table 3 Comparison of kinematic and temporal parameters between the condition without racket (WOR) and with racket (WR) for the forward propulsion (a) and the backward propulsion (b)

a	Without racket	With racket	Comparison	
	Mean(SD)	Mean(SD)	<i>p</i>	<i>d</i>
Propulsion technique parameters				
PP_{mean} (s)	0.43(±0.16)	0.46(±0.17)	0.008	0.225
DP_{mean} (s)	0.39(±0.15)	0.41(±0.15)	0.011	0.220
Performance parameters				
ST_{mean} (s)	2.07(±0.73)	2.19(±0.78)	<0.001	0.414
TT_{mean}¹ (s)	0.39(±0.23)	0.41(±0.28)	0.806	0.021
V_{max} (m/s)	4.66(±0.63)	4.49(±0.68)	<0.001	0.390
V_{mean} (m/s)	3.12(±0.40)	2.99(±0.49)	<0.001	0.416
V_{peak} (m/s)	3.26(±0.78)	3.06(±0.92)	0.017	0.202
A_{mean} (m/s²)	6.30(±2.22)	5.68(±1.75)	<0.001	0.374
D_{mean} (m/s²)	11.15(±4.27)	9.92(±4.01)	<0.001	0.417

b	Without racket	With racket	Comparison	
	Mean(SD)	Mean(SD)	<i>p</i>	<i>d</i>
Propulsion technique parameters				
PP_{mean} (s)	0.50(±0.20)	0.43(±0.15)	<0.001	0.311
DP_{mean} (s)	0.37(±0.13)	0.39(±0.14)	0.105	0.138
Performance parameters				
ST_{mean} (s)	2.29(±0.63)	2.19(±0.78)	<0.001	0.453
TT_{mean}¹ (s)	0.43(±0.25)	0.41(±0.28)	<0.001	0.344
V_{max} (m/s)	4.16(±0.53)	4.49(±0.68)	<0.001	0.461
V_{mean} (m/s)	2.84(±0.36)	2.99(±0.49)	<0.001	0.416
V_{peak} (m/s)	3.09(±0.68)	3.06(±0.92)	<0.001	0.398
A_{mean} (m/s²)	6.14(±1.89)	5.68(±1.75)	0.590	0.046
D_{mean} (m/s²)	10.05(±3.97)	9.92(±4.01)	<0.001	0.274

With SD: standard deviation; *p*: *p*-value fixed at 0.05; *d*: effect size

¹: transition time from forward propulsion to backward propulsion; ²: transition time from backward propulsion to forward propulsion.

Comparison of delta with forward propulsion vs. backward propulsion

The results of comparing the delta obtained between the forward propulsion and the backward propulsion are presented in Table 4. The only significant differences are TT_{mean} and PP_{mean} which are slightly higher in backward propulsion compared to forward propulsion, and A_{mean} which is slightly lower in backward propulsion compared to forward propulsion.

Table 4 Comparison of the delta between the condition forward propulsion and the backward propulsion

Δ (Without racket – With racket)				
FP		BP		Comparison
Mean (SD)		Mean (SD)		<i>p</i>
				<i>d</i>

Propulsion technique parameters				
ΔPP_{mean} (s)	-0.04(±0.22)	0.06(±0.21)	<0.001	0.388
ΔDP_{mean} (s)	-0.03(±0.17)	-0.02(±0.16)	0.660	0.032
Kinematic parameters				
ΔST_{mean} (s)	-0.20(±0.58)	-0.18(±0.54)	0.741	0.028
ΔTT_{mean} (s)	-0.01(±0.21)¹	0.07(±0.26)²	<0.001	0.299
ΔV_{max} (m/s)	0.16(±0.56)	0.17(±0.46)	0.696	0.029
ΔV_{mean} (m/s)	0.13(±0.39)	0.11(±0.34)	0.331	0.090
ΔV_{peak} (m/s)	0.22(±1.09)	0.26(±0.77)	0.207	0.107
ΔA_{mean} (m/s ²)	0.67(±2.19)	0.07(±1.94)	<0.001	0.285
ΔD_{mean} (m/s ²)	1.32(±3.86)	0.84(±3.65)	0.138	0.109

With SD: standard deviation; p: p-value fixed at 0.05; d: effect size for the significant difference

¹: transition time from forward propulsion to backward propulsion; ²: transition time from backward propulsion to forward propulsion.

Discussion

The analysis conducted in this article represents to our knowledge, the first of its kind in the field of wheelchair badminton. The primary objective of this study was to analyze the impact of the badminton racket, on spatiotemporal parameters, in both forward propulsion and backward propulsion. It has been hypothesized that the use of a badminton racket will induce modifications in propulsion technique parameters and a decrease in performance parameters, leading to an overall reduction in athletes' performances. This hypothesis was partially confirmed since the significant differences observed are in line with the initial assumptions. However, a decrease in the transition time and the first propulsion phase when the racket is employed in backward propulsion has been observed, which is against the hypothesis. Moreover, all the considered parameters do not seem to be affected when using the racket such as transition time in forward propulsion and last deceleration in backward propulsion. Nevertheless, these findings suggest a negative impact of racket utilization on athletes' performance during wheelchair propulsion on velocity, acceleration, and deceleration of athletes. The second objective was to assess whether the badminton racket's impact is more pronounced in one propulsion direction compared to the other. It was hypothesized that the badminton racket effect will be greater in backward propulsion compared to forward propulsion. However, this hypothesis was not confirmed, as only the transition time, first propulsion phase, and the maximum velocity showed significant differences with opposite results. This is insufficient to assert that the impact of the racket is more pronounced in backward vs. forward propulsion. On the other hand, it appears that the direction of propulsion does not increase the impact of the racket, but rather modifies it, as the parameters are affected differently depending on the direction of propulsion considered. Overall, the racket seems to have modify athlete's propulsion technique and have a negative effect on athlete's performance

Impact of the racket in forward propulsion

Regarding the propulsion technique parameters in forward propulsion, the use of the badminton racket seems to increase both the propulsion and deceleration phase times. While these results are not directly associated with the athlete's performance, they suggest a potential alteration in the propulsion technique by slowing down the propulsion and deceleration movements of athletes. These findings are consistent with studies involving racket use in tennis or badminton, where a similar parameter related to propulsion phase time was influenced by the discomfort arising from the racket's weight and dimensions (Alberca et al., 2022a; de Groot et al., 2017).

Regarding performance parameters, the use of the badminton racket appears to decrease athletes' velocity (maximum and mean and, peak), acceleration and deceleration, in association with an increase in sprint time. Those results leading to a decrease of the athlete's performance and can be explained by more difficulties in coupling between the hand and the handrim. Alberca et al. (2022a) had demonstrated a modification in the athlete's force application in a way that is generally related to lower propulsion effectiveness when using a badminton racket in submaximal conditions with parameters such as fraction of effective force or push angle. Their temporal findings also suggest an alteration in the propulsion technique when employing a racket (2022a). It can be imagined here that the same thing happens: wheelchair badminton players modify their propulsion technique due to limitations imposed by the badminton racket, preventing them from fully grip the handrim. This constraint complicates their capacity to exert optimal propulsion forces, leading to a decrease in athlete's velocity, acceleration, and deceleration.

Impact of the racket in backward propulsion

In the context of backward propulsion, the use of the racket results in similar reductions in velocity, emphasizing its negative impact on athlete's performance. However, several findings differ from those observed in forward propulsion. Specifically, using the racket decreases the backward propulsion phase time while increasing it in forward propulsion, indicating a shortened athlete propulsion gesture. These reduction may stem from the wheelchair configuration, as highlighted by Mason et al. (2015), in conjunction with racket use. Indeed, the athlete's wheelchair is optimized for forward propulsion, although backward propulsion is equally important in wheelchair badminton. By adding the use of the racket, which prevents gripping the handrim, it can be assumed that athletes reduce their gesture due to interference with the wheelchair's backrest, resulting in a reduction of their first propulsion phase time.

Additionally, the racket reduces the backward transition time, unlike forward propulsion where no difference is noted. It is also noteworthy that the use of the racket does not seem to influence the duration of the backward deceleration phase or acceleration, two parameters that undergo modifications in forward propulsion with the racket. Those disparities in the racket impact observed between forward and backward propulsion in the deceleration phase time, transition time, and acceleration results can be elucidated by the distinctive pattern of backward propulsion. When an athlete applies brakes to transition from forward to backward propulsion or accelerates from a stationary position, the motion involves an initial pulling phase on the lower front part of the wheel. In contrast, in forward propulsion, the motion is initiated by a pushing phase on the top of the wheel. It is conceivable that this pulling movement on the lower front part of the wheel facilitates the grip between the hand with the racket and the handrim, compensating for coupling difficulties present in forward propulsion (Alberca et al., 2022a; Alberca et al., 2022b; de Groot et al., 2017; Fukui et al., 2020; Goosey-Tolfrey & Moss, 2005). In this context, the racket doesn't seem to negatively impact the deceleration phase time, transition time and acceleration in backward propulsion.

Impact of the racket based on the propulsion direction

Finally, it was investigated whether the impact of the racket is more pronounced in one direction of propulsion compared to the other. The results of the calculated deltas showed that only three parameters have significant results, and in opposite ways. Indeed, the impact of the racket appears to be significantly more important in backward propulsion regarding transition time and first propulsion phase, and vice versa for maximum velocity, which seems to be more affected using the racket in forward propulsion. These contradictory results are insufficient to establish that the impact of the racket is more pronounced in one direction of propulsion. Those findings indicate that the racket has an impact that varies depending on the direction of propulsion, but it is not predominantly influenced by either one.

Limitations

As a main limitation of this study is that no additional analyses were carried out to distinguish the results based on athlete classifications. This choice was made due to the complexity of the analysis. Indeed, this study already investigates the impact of the racket based on the direction of propulsion. Introducing an additional parameter into the analysis would have made the results more challenging to interpret. Furthermore, considering the sample size for this study, including athlete classification as an additional parameter could have weakened the statistical power of the analyses performed. However, it is important to note that athlete classification is a relevant factor that will be the subject of a future publication.

Conclusion

To conclude, this study has highlighted the following points:

- The use of a badminton racket modifies propulsion technique parameters differently depending on the considered propulsion direction: longer gesture in forward propulsion and shorter gesture in backward propulsion
- The use of a badminton racket has a negative impact on performance parameters in a global way, which is consistent with a decrease in the performance of the athlete especially on the sprint time, velocity, acceleration, and deceleration of the athletes.
- The impact of the racket is different in one direction of propulsion compared to the other but is not increased by one or the other.

These results underscore the importance of exploring solutions to optimize the interface between the hand, racket, and handrim in wheelchair badminton. Such optimizations hold the potential to significantly enhance the performance of the athletes involved. As mentioned in the introduction, future investigations could focus on testing novel handrim shapes or alternative grip textures for both the handrim and racket handle.

To comprehensively analyze the biomechanics of wheelchair badminton, a comparative assessment based on the athletes' classification would be of great interest. The classification system is closely intertwined with the athletes' abilities and incorporating this factor would enable us to tailor racket improvements specific to each athlete's needs. Furthermore, supplementing the analysis with kinetic data to derive force and moment parameters could offer insights into the risk of injury to athletes. This approach would foster the inclusion of injury prevention considerations alongside performance enhancements in our research objectives.

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Declaration of interest statement

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