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Impact of dribbling on spatiotemporal and kinetic parameters in wheelchair basketball athletes

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Abstract

Background: Wheelchair basketball is one of the most popular Paralympic sports. Dribbling a ball while propelling is a key feature of wheelchair basketball. Very few studies have investigated the biomechanical impact of dribbling. This study aims to analyze the impact of dribbling on the amplitude and symmetry of spatiotemporal and kinetic parameters of wheelchair propulsion.

Methods: Ten experienced wheelchair basketball athletes (31.5 ± 10.6 years old; 7 men, 3 women) with various classifications performed eight 9-m sprints along a straight line on a basketball court: four sprints using classic synchronous propulsion, and four sprints while dribbling a ball down the court.

Findings: Dribbling decreased velocity, mean propulsive moments and the force rate of rise, as well as increased push time, force rate of rise asymmetry and angular impulse asymmetry. All kinetic variables were asymmetric and higher on the dominant limb.

Interpretation: The combination of reduced velocity and propulsive moments when dribbling indicates that wheelchair basketball athletes may deliberately preserve a safety margin of acceleration to adapt to uncontrolled ball rebounds. Dribbling was not associated with any factors associated with an increased risk of musculoskeletal disorders.

Keywords

Biomechanics; wheelchair sport; adaptative sport; performance; injuries

Introduction

Wheelchair basketball (WB) is one of the most popular Paralympic sports that provides high-level professional competition (Veeger et al., 2019). According to the International Wheelchair Basketball Federation (IWBF) classification system, each WB player is assigned a classification based on the range of positions the athlete can reach without touching the chair (Costa et al., 2018). The classification system in Canada, which closely reflects the IWBF's system and also allows able-bodied athletes, ranges from 1 point (players with the least ability) to 4.5 points (minimal or no disorder). Like classic basketball, performance in WB is founded on endurance, strength, velocity, coordination and mobility (Cavedon et al., 2014; Iturricastillo et al., 2015; Molik et al., 2017). More specifically, an athlete's performance is determined by three constantly interacting factors: their physical performance (e.g., cardiorespiratory capacity, endurance), their mobility performance (what they can do with their wheelchair) and their game performance (e.g., performing specific WB manoeuvres such as throwing, blocking, passing, etc.) (de Witte et al., 2016).

While performance is paramount in WB, preventing musculoskeletal disorders (MSD) is certainly another key aspect to consider. The prevalence rate of shoulder pain in persons with a spinal cord injury is 31% to 73%, and the prevalence rate for carpal tunnel syndrome (CTS) is 49% to 73% (Boninger et al., 2005). More than 70% of WB athletes have experienced persistent shoulder pain since starting this sport (Curtis and Black, 1999). Curtis and Dillon (1985) showed that WB players are the second most injured athletes in wheelchair-related sports after wheelchair racers. WB itself can cause or exacerbate MSD. The heavy physical and mechanical demands of WB, coupled with the necessity to regularly raise the hands over the shoulders, are determinants and predictors for pain and injuries (Akbar et al., 2015; Curtis and Black, 1999; Wilroy and Hibberd, 2018). Increasing the forces applied on the pushrims increases the shoulder load (Desroches et al., 2010; Koontz et al., 2005; Kulig et al., 2001) and is related to the development of shoulder pain (Curtis and Dillon, 1985). These high pushrim forces, most notably their rate of rise, are also associated with CTS (Boninger et al., 2005).

A unique feature of WB is dribbling, which requires both game performance and mobility performance. De Witte et al. (2017) revealed that ball possession decreases the mobility performance of athletes. However, to our knowledge, no study has provided biomechanical insight such as spatiotemporal parameters (e.g., velocity, push time) or kinetic parameters (e.g., propulsive forces, impulse) related to dribbling. However, this information is needed to better understand the requirements of this task and to assess shoulder risk exposure.

Similarly, asymmetry in kinetic parameters, which has seldom been studied in manual wheelchair propulsion (Bergamini et al., 2015; Nyland et al., 1997; Schnorenberg et al., 2014; Soltau et al., 2015), is typically related to dominance of the upper limb (Nyland et al., 1997) and warrants attention in terms of improving performance and decreasing the risk of MSD (Faupin et al., 2013; Hurd et al., 2008; Liping Qi et al., 2014). Symmetry is indeed typically associated with improved performance (Bergamini et al., 2015). Oppositely, asymmetry may increase the shoulder load on the dominant side and exacerbate the risk of MSD.

The objective of our study was to analyze the impact of dribbling on the amplitude and symmetry of spatiotemporal and kinetic parameters related to mobility performance (which we defined as the maximal wheelchair velocity) and risk of MSD in WB athletes. From a performance perspective, we hypothesized that dribbling would decrease velocity, and that this decrease would be caused by a lower impulse applied to the pushrims due to a push time decrease. From an MSD perspective, since dribbling would reduce the push time, we hypothesized that dribbling would also reduce the push angle, and would increase the total pushrim force value and rate of rise, metrics which are associated with an increased risk of MSD (Boninger et al., 2005).

Methods

Participants

A total of 10 experienced WB athletes participated in this experiment. Players could be disabled or able-bodied, but they had to be practicing WB for at least 3 years and had to be regularly involved in competitions. Our exclusion criterion was any current or recent (≤3 months) injury or pain that could interfere with wheelchair propulsion. The experimental protocol was approved by the Institutional Research Ethics Committee of the Université du Québec à Montréal (certificate #CIEREH 2879_e_2018). Participant demographics are presented in Table 1.

Table 1: Participant demographics

Participant	Sex (M/F)	Age (years)	Dominant limb (R, L)	Disorder	Height (m)	Weight (kg)	BMI (kg/m^2)	Experience (years)	Classification (Canadian scale) (1.0 – 4.5)
1	F	31	R	Spinal cord injury (T6, A)	1.60	61	23.8	3	1.0
2	M	60	R	Spinal cord injury (D6-D7, A)	1.83	71	21.2	6	1.0
3	M	29	L	Cerebral palsy	1.68	60	21.3	10	1.0
4	M	34	R	Spinal cord injury (T7, A)	1.50	73	32.4	10	1.5
5	M	33	R	Spinal cord injury (T10, A)	1.76	95	30.7	1.5	2.0
6	M	32	R	Muscular dystrophy	1.73	52	17.4	6	2.0
7	M	23	R	Spastic dysplasia	1.63	58	21.8	11	2.0
8	F	30	R	Non-disabled	1.61	62	23.9	3	4.5
9	M	19	R	Non-disabled	1.75	75	24.5	10	4.5
10	M	24	R	Non-disabled	1.78	78	24.6	16	4.5
Mean (SD)	7M 3F	31.5 (10.6)	R = 9 L = 1	/	1.69 (0.10)	68.5 (12.6)	24.2 (4.5)	7.7 (4.5)	2.4 (1.5)

Protocol

After a 5-minute freestyle warm-up, each participant performed eight sprints in a straight line from a stopped position over a 9-m distance on a wooden basketball court: four of these sprints were conducted with classic propulsion (CP) and four were performed with dribble propulsion (DP). For both conditions, participants were instructed to propel as fast as possible until they crossed the finish line. Participants were asked to propel synchronously (with both arms pushing at the same time) for each trial. For the

DP condition, participants were asked to forward dribble during the sprint, as pictured in Figure 1. After two acceleration pushes, the participants had to push the ball forward (A), push the pushrims (B, C, D), recover the ball on the rebound (E), then place the ball back onto their knees (F). Participants were asked to perform this sequence as many times as possible during the 9-m sprint. The order of the conditions was randomized, and participants were allowed to rest for a self-selected duration between trials to prevent the development of a state of muscular fatigue.

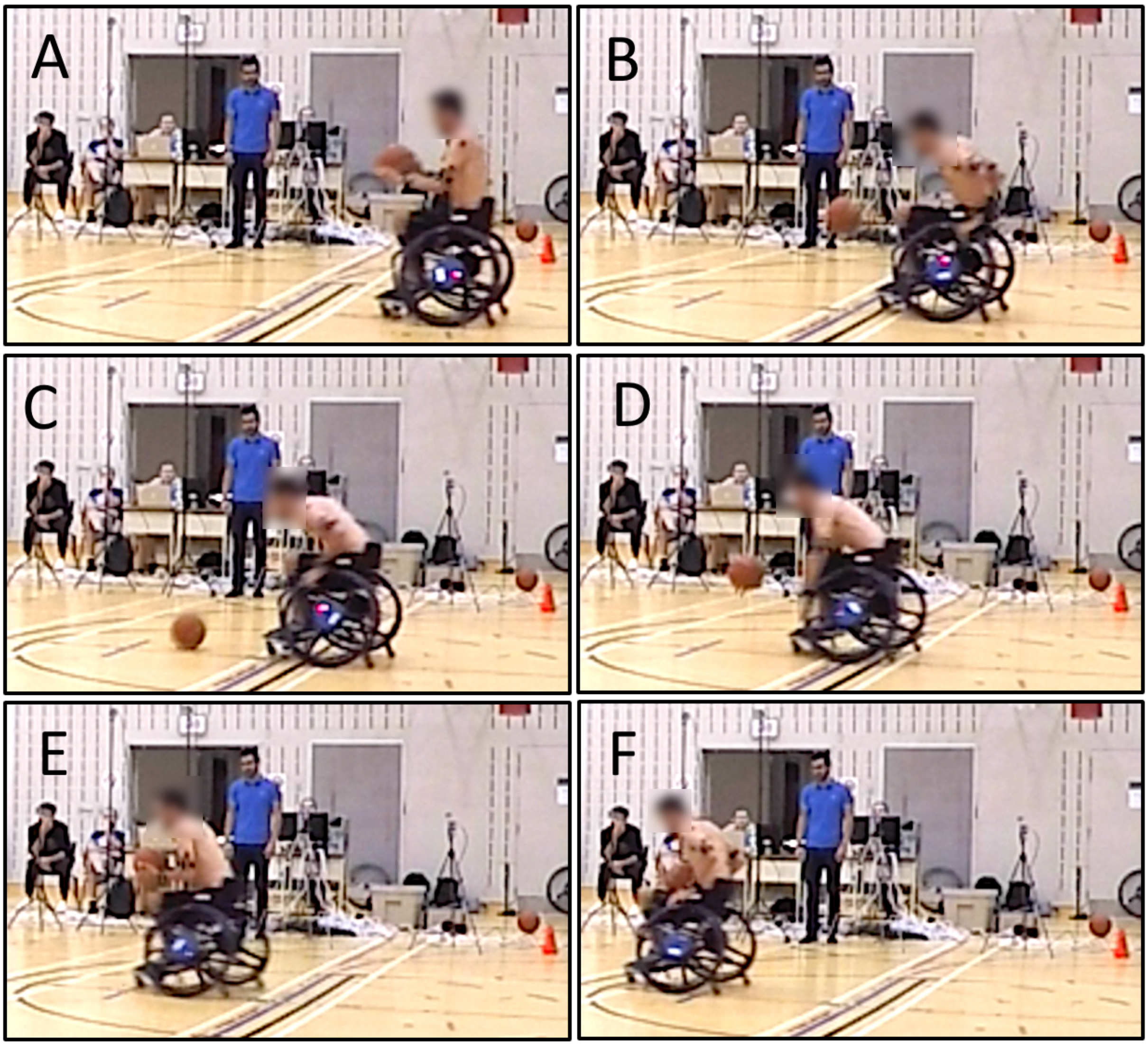

Figure 1: Sequence of a successful dribbling task; A) pushing the ball forward with wheelchair in motion; B) push initiation; C) ball rebound; D) push end; E) ball recovery; F) putting the ball on the knees.

Measurement tools

Participants used their own sports wheelchair equipped bilaterally with two instrumented wheels (SmartWheel). These wheels have a weight and moment of inertia of approximately 4.9 kg and 0.15 $kg{\cdot}m^2$ (Sprigle et al., 2016). A wheel size of 25 or 26 inches was selected based on the participant's wheelchair to closely match the size of their own wheels. To better reflect regular game conditions, the default SmartWheel tires were switched to inflatable tires and fully inflated to 110 PSI, which reduces rolling resistance and therefore improves mobility performance (Sawatzky et al., 2004). The wheels were cambered according to each participant's wheelchair adjustment, with a camber angle of 19° ± 2° measured using an optoelectronics system (Optitrack). The wheel angle θ, forces F_x, F_y, F_z, and moments of force M_x, M_y, M_z applied by the participants on both pushrims, were measured bilaterally at 240 Hz during all data acquisition sessions. Entire data acquisition periods were filmed using a GoPro Hero4 camera at 30 fps.

Data processing

The dynamic kinetic offsets due to wheel cambers were cancelled as described in Chénier et al. (2017). The wheelchair velocity was calculated based on the wheel angles, using a 131-point first-order derivative Savitzky-Golay filter (Chénier et al., 2015).

All pushes were segmented manually based on a threshold of 40 N on the total force ($F_{\text{tot}} = \sqrt{F_x^2 + F_y^2 + F_z^2}$). For the CP condition, pushes 3, 4 and 5 were analyzed (the first two pushes were considered transitional). For the DP condition, a push was deemed valid if, according to a video analysis using the GoPro camera, it was performed while the basketball was in the air and if the participants recovered the ball with two hands in front of them. These criteria were chosen to define a typical, repeatable dribble technique to ensure that the analyzed pushes were similar. Pushes that failed to meet these criteria were excluded.

The following outcome measures were calculated and averaged over the selected pushes except for velocity, which was defined as the velocity reached at the end of the fourth push.

Parameters related to performance:

- Velocity in m/s;
- Push time (PT) in s: Coupling time between the hand and the pushrim for each push;
- Mean propulsive moment ($M_{\text{z mean}}$) in Nm: Mean moment around the axis of rotation, responsible for the forward movement of the wheelchair;
- Angular impulse in Nm·s, calculated as $M_{z\,\text{mean}} \cdot \text{PT}$.

Parameters related to MSD:

- Push angle (PA) in degrees: Wheel angle course during push time;
- Peak total force ($F_{\text{tot peak}}$) in N: Peak of the total force F_{tot} applied by the hand on the pushrim;
- Force rate of rise (RoR) in N/s: Slope of the line from F_{tot} at push initiation to the first peak of F_{tot}.

Parameter symmetry was calculated using the following asymmetry index (AI) developed by Hurd et al. (2008):

$$AI = |(1 - (x_{\text{D}}/x_{\text{ND}}))|$$

Where x is the calculated parameter, D corresponds to the dominant side and ND to the non-dominant side. For perfect symmetry, AI is 0. This index was chosen because it follows a normative or Gaussian distribution, which avoids problems due to the lack of linearity of the indices (Hurd et al., 2008). The asymmetry index was calculated for all the parameters except for velocity since propulsion was performed in straight line and the velocity could therefore not be asymmetrical.

All data processing and calculations were performed using Python/SciPy and the Kinetics Toolkit library (Chénier, 2021).

Statistical analysis

Including the velocity, a total of 13 variables were calculated: PT, $M_{z\,\text{mean}}$, Angular impulse, PA, $F_{\text{tot peak}}$ and RoR were computed separately on both sides before being averaged. Their asymmetry indices were also computed. For each variable, the data normality of the paired differences between both conditions was verified using a Shapiro-Wilk test with $\alpha = 0.05$. Whenever the normality of the data was confirmed, parametric tests (paired t-tests) with $\alpha = 0.05$ were used to test for the mean difference between both propulsion conditions. Due to the exploratory nature of this work, the significance thresholds were not corrected for multiple comparisons and results were interpreted accordingly. The effect size was reported for each comparison using:

$$d = \frac{\text{mean}_{\text{CP}} - \text{mean}_{\text{DP}}}{\text{stdev}_{\text{CP}}}$$

and was interpreted according to Cohen et al. (1988): small ($d = 0.2$), moderate ($d = 0.5$) and large ($d = 0.8$). For data that failed the Shapiro-Wilk normality test, non-parametric tests (Wilcoxon signed rank tests) were used instead, and the effect size was calculated using the rank-biserial correlation. Statistics were computed using JASP software (JASP Team, 2020).

Results

Table 2 shows all the outcome measures for both propulsion conditions. These results are also presented individually in Figure 2.

For the parameters related to performance, dribbling had a large effect on velocity (-0.21 m/s, -8%, $p < 0.001$, $d = -1.50$), on push time (+0.03 s, +14%, $p = 0.019$, $d = 0.91$) and on mean propulsive moments (-1.42 Nm, -6%, $p = 0.002$, $d = -1.347$). Dribbling also moderately increased impulse asymmetry (+0.07, $p = 0.045$, $d = 0.732$) and may have moderately increased impulse (+0.52 Nm·s, +11%, $p = 0.075$, $d = 0.637$) and propulsive moment asymmetry (+0.08, $p = 0.09$, $d = 0.6$).

For the parameters related to MSD, dribbling had a large effect on both the mean and asymmetry of force rate of rise, with a mean decrease of 1592 N/s (-32%, $p = 0.007$, $d = -1.11$) and an asymmetry index increase of 0.93 ($p = 0.027$, $d = 0.78$). Dribbling may have moderately decreased the peak total force (-10.9 N, -5%, $p = 0.09$, $d = -0.60$).

Figure 3 shows the time-normalized profile of the total force (F_{tot}) during both propulsion conditions for low-point (1 to 2.5) participants and high-point (3 to 4.5) participants. Dribbling seemed to delay (for low-point participants) or decrease (for high-point participant) the slope of the force, independently of the push time.

Table 2: Mean and standard deviation of the measured outcome variables in both propulsion conditions

Parameters		**CP**	**DP**	**DP - CP**	**p**	**Effect size d**
Parameters related to performance						
Velocity	Mean (m/s)	2.78 (0.31)	2.56 (0.36)	-0.21 (0.14)	**< .001**	**<u>-1.504</u>**
Push time (PT)	Mean (s)	0.22 (0.02)	0.24 (0.01)	0.03 (0.03)	**0.019**	**<u>0.907</u>**
	AI	0.10 (0.04)	0.12 (0.06)	0.02 (0.07)	0.407	0.275
Mean propulsive moment ($M_{z\ mean}$)	Mean (Nm)	22.99 (5.94)	21.57 (6.08)	-1.42 (1.05)	**0.002**	**<u>-1.347</u>**
	AI	0.17 (0.12)	0.25 (0.25)	0.08 (0.14)	0.090	**0.600**
Angular impulse	Mean (Nm·s)	4.94 (1.06)	5.46 (1.55)	0.52 (0.82)	0.075	**0.637**
	AI	0.15 (0.10)	0.22 (0.17)	0.07 (0.09)	**0.046**	**0.732**
Parameters related to musculoskeletal disorders						
Push angle (PA)	Mean (°)	91.9 (5.8)	90.9 (8.1)	-1.0 (11.1)	0.780	-0.091
	AI	0.11 (0.04)	0.13 (0.07)	0.02 (0.08)	0.426	0.264
Peak total force ($F_{tot\ peak}$)	Mean (N)	226.9 (51.8)	216.0 (45.3)	-10.9 (18.3)	0.090	**-0.600**
	AI	0.19 (0.09)	0.20 (0.11)	0.02 (0.07)	0.497	0.224
Force rate of rise (RoR)	Mean (N/s)	5036 (1585)	3444 (1369)	-1592 (1431)	**0.007**	**<u>-1.112</u>**
	AI	0.66 (0.37)	1.60 (1.85)	0.93 (1.85)	**0.027***	**<u>0.782</u>**

Legend:

Mean: Average over both sides. AI: Asymmetry Index.

Statistically significant differences ($p < 0.05$) are indicated in bold font. **Moderate** ($d \approx 0.5$) and **<u>large</u>** ($d \approx 0.8$) effect sizes are indicated in bold and underlined font.

*A Wilcoxon test has been performed instead of a paired t-test. Effect size is given by the matched rank biserial.

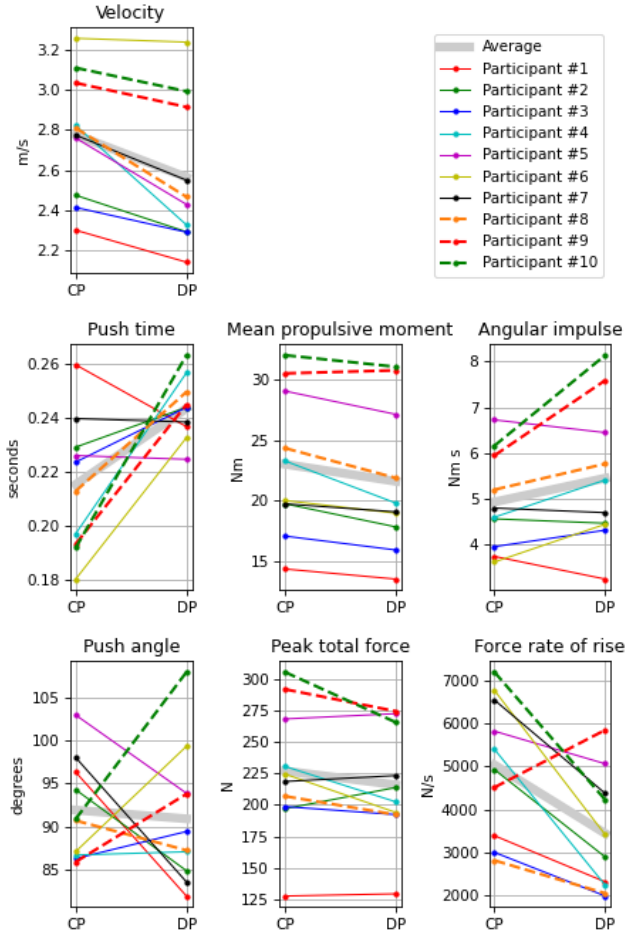

Figure 2: Outcome variables in both propulsion conditions for every participant

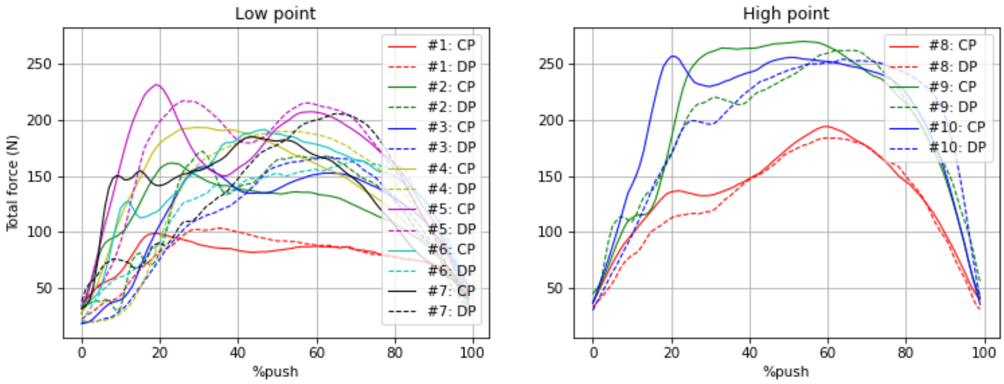

Figure 3: Total force profile in both propulsion conditions for low-point and high-point participants

Discussion

Our research aimed to study the impact of dribbling on spatiotemporal and kinetic parameters related to velocity and upper limb MSD risk exposure. As hypothesized, dribbling had a negative impact on velocity. This result aligns with Kozomara et al. (2019) who observed an increase in sprint time among wheelchair basketball athletes when dribbling.

This decreased velocity was accompanied by decreased mean propulsive moments. This reduction is interesting for such a maximal-speed task because the typical muscle force-velocity relation would usually predict a muscular force increase. Therefore, although they were asked to propel as fast as they could, they did not during dribbling. This may have been deliberate to preserve an acceleration margin to recover the ball in case it bounced farther away than expected.

We initially expected that the reduced velocity would be partly due to a decrease in push time; however, the push time increased instead. Contrary to our hypothesis, the athletes did not change the push angle between conditions. Therefore, since they went slower during dribbling, they had more time in contact with the wheel. This increased push time compensated for the decreased propulsive moments, letting the impulse unaffected if not slightly increased. Whereas this seems contradictory to the reduced velocity, we hypothesize this is explained by a combination of 1) the additional time needed to handle the ball, providing more time for the wheelchair to decelerate between the pushes, and 2) by the inertial action of the ball, which pushes the wheelchair backward both during the dribble initiation and completion.

The longer push time also certainly contributed to the reduction in the force rate of rise. However, as observed in Figure 3, even when normalized for time, dribbling seems to delay or attenuate the force rise. Therefore, dribbling seems to induce a fundamental change in the force generation sequence, requiring WB athletes more time to reach the peak force within the push phase. Separating Figure 3 into two classes (low-point and high-point athletes) highlights the tendency of the low-point athletes to not only delay reaching peak force but also the start of the force rise. When they dribbled, they grabbed the wheels and applied some force on the pushrims, then waited between 5% and 15% of the push phase before increasing this force to propel the wheelchair. This behaviour was not observed in classic propulsion or in either condition with the high-point athletes.

Participants with the lowest points had the most impaired trunk control. We believe this behaviour when dribbling may have been caused by the complex sequence of movements required to perform the task (pushing the ball forward, pulling the hands backwards to prepare themselves to push the wheels, pushing the wheels, preparing themselves to recover the ball). In athletes with reduced trunk control, the large thoracohumeral muscles are challenged as they need to conciliate two key imperatives: generating sufficient strength to manoeuvre the wheelchair and manipulate the ball, and maintaining dynamic postural stability (Gagnon et al., 2009). This complex sequence may have been difficult to achieve for these athletes. As such, it is possible that they contact the wheel first to stabilize before they start propelling.

We observed a high level of asymmetry (more than 0.1) toward the dominant side with each kinetic variable and independently of the propulsion condition. We know that sports wheelchairs are more manoeuvrable than standard wheelchairs to address certain performance needs. This high manoeuvrability could increase the variability of the forces produced to steer the wheelchair, which would explain these high asymmetry index values. Given that athletes can change the direction of their wheelchair just by moving their body (Marquis et al., 2019), dribbling the ball might be sufficient to slightly deviate the wheelchair and thus require the athlete to compensate on the next push.

In addition to purely biomechanical causes, the decreased propulsive moments and increased asymmetry during dribbling could also be due to the performance of a dual task, namely propelling the wheelchair and dribbling the ball. The performance of both simultaneous tasks is likely to be reduced by capacity interference determined by the degree of attention required for both tasks (Price et al., 2009). Since dribbling is a complex task, it requires greater attention, which leaves less resources for propelling (Styles, 2005).

Since wheelchair basketball is a source of pain and MSD, it is important for sports teams to be aware of any training issues that could impact the MSD risk (Lepera, 2010). The results of our study suggest that while WB athletes' velocity is reduced when dribbling, WB athletes adapt and change their propulsion technique in a way that increases the asymmetry, but decreases the mean propulsive moment, increases the push time, decreases the total force, and decreases the force rate of rise. From a kinetics perspective, this is viewed as a beneficial adaptation to protect the neuromusculoskeletal integrity of the upper body (Boninger et al., 2000, 2005; Consortium for Spinal Cord Medicine, 2005). The highly reduced force rate of rise may be especially beneficial for the wrist median nerve (Boninger et al., 2005). Thus, wheelchair dribbling does not appear to be performed at a greater risk than classic propulsion from a kinetics point of view. However, future research should assess the biomechanical impact of ball handling since this task is often done with raised arms and could constitute an additional risk factor, especially for the shoulders (Akbar et al., 2015).

We believe that the main limitation of our study is its small cohort of only 10 participants. However, we are confident that a larger cohort would have strengthened our results because of our estimated effect sizes, which were characterized as moderate to high. In addition to this limitation, using SmartWheel instrumented wheels increased the weight of the wheels, and thus the rolling resistance and wheelchair inertia. However, these effects were limited by the use of fully inflated tires instead of the standard solid Smart Wheel tires.

Conclusions

The objective of our study was to analyze the impact of dribbling on the amplitude and symmetry of spatiotemporal and kinetic parameters in wheelchair basketball athletes. When dribbling, the athletes' velocity decreased and was accompanied by a decrease in the mean propulsive moments. These reductions in propulsive moments may be due to a combination of a deliberate reduction to adapt to rebounds that could be farther away than expected, and a reduction in capacity interference due to the dual task of propelling and dribbling. Dribbling induced a delay in the force production sequence in athletes with reduced trunk control, which may indicate a need to stabilize the trunk and upper body using the pushrims after pushing the ball forward. This highlights the importance of considering athletes' classifications when evaluating sport-related tasks. Even for these a priori symmetric tasks, the high asymmetry observed in all parameters reminds us that wheelchair propulsion is an asymmetric task, especially in wheelchair sports. Lastly, based on the measured spatiotemporal and kinetic parameters, we found no evidence of a greater risk of MSD when dribbling.

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Declaration of interest statement

The authors do not report any conflicts of interest. The authors alone are responsible for the written content of this article.

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