Effects of synchronous versus asynchronous mode of propulsion on wheelchair basketball sprinting

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Abstract

Objective: This study aimed to first investigate synchronous (SYN) versus asynchronous (ASY) mode of propulsion and, second, investigate the wheel camber effects on sprinting performance as well as temporal parameters. Method: Seven wheelchair basketball players performed four maximal eight-second sprints on a wheelchair ergometer. They repeated the test according to two modes of propulsion (SYN and ASY) and two wheel cambers (9° and 15°). Results: The mean maximal velocity and push power output was greater in the synchronous mode compared to the asynchronous mode for both camber angles. However, the fluctuation in the velocity profile is inferior for ASY versus SYN mode for both camber angles. Greater push time/cycle time (Pt/Ct) and arm frequency (AF) for synchronous mode versus asynchronous mode and inversely, lesser Ct and rest time (Rt) values for the synchronous mode, for which greater velocity were observed. Conclusions: SYN mode leads to better performance than ASY mode in terms of maximal propulsion velocity. However, ASY propulsion allows greater continuity of the hand-rim force application, reducing fluctuations in the velocity profile. The camber angle had no effect on ASY and SYN mean maximal velocity and push power output.

Keywords

Power output, velocity, wheelchair ergometry, wheel camber

Introduction

For individuals with disabilities, wheelchair propulsion pattern is of cyclic and repetitive nature similar to bipedal and cycling pattern but could be considered as a complex and very variable pattern. In fact, if we consider two wheelchair users exercising at a similar power output, clear differences in choice of push frequency and propulsion techniques would be evident. Several researchers have examined different propulsion strategies in manual wheelchair propulsion such as forward versus reverse [1,2] and synchronous (SYN) versus asynchronous (ASY) push-rim methods [3,4]. Among them, the synchronous mode is described by Goosey-Tolfrey and Kirk [5] as work that is done by both arms in unison in order to exert force at the same moment on the hand-rims. On the other hand, asynchronous propulsion is described as work done by the arms in an alternate fashion, so that at each contact time, only one arm applies force on the hand-rim [5]. In wheelchair basketball, some players adopted an asynchronous push strategy in some phases of the game [5], which could probably allow players to have better control and mastery of their wheelchair, required for more accurate dribbling action and for acceleration after a pivot, by increasing the time of contact with the hand-rims.

In the wheelchair literature, physiological responses (VO₂, HR, gross caloric output) of SYN or ASY mode of propulsion show contradictory results. Indeed, during submaximal push strategy tasks (SYN versus ASY), Glaser et al. [3] found significantly
Wheelchair propulsion and basketball performance

Participants

This study was performed with seven male participants who were all members of the same wheelchair basketball club in the French elite Championship. The means and standard deviations (SDs) of the anthropometric data (age, mass, height, disability, classification, daily training hours) are given in Table 1. For the international competition, players are placed into eight classification levels for participation (from 1 to 4.5), based on the International Wheelchair Basketball Federation [12]. Class 5 is only used for able-bodied participants in the “French Handisport Federation” classification. All participants were fully informed of any risks before giving their written informed consent to participate in these experiments. The experimental procedures were approved by the local hospital ethics committee and complied with the ethical standards of the 1975 Helsinki Declaration.

Materials and methods

Participants

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Materials

All participants used the same wheelchair (Top End X-Terminator, Invacare Corporation®, Elyria, OH) designed for basketball for each trial. The weight and length was 13 kg and 80 cm, respectively. The angle between the back and the seat was fixed at 75°, the seat was inclined by 15° and the back was placed vertically. The height of the back was 28 cm, while the depth and width were 42 cm and 39 cm, respectively. The diameter of the wheels was 64 cm; the tube tires were inflated to 8 bars. According to previous studies focusing on wheelchair propulsion mode [4–6,10], no individual adjustments relative to anthropometrics of the participants were made. A standardized chair configuration eliminated effects of wheelchair design/setup on measurements [6].

The wheelchair was placed on an original ergometer (VP100 HANVI, HEB TEC Machine®, Andrezieux-Boutheon, France, Figure 1) comprised of a system of two pairs of independent rollers [13]. This ergometer was adapted on the lines of the VP100 HTE ergometer validated and presented by Devillard et al. [14]. The ergometer was equipped with two electromagnetic brakes

### Table 1. Individual and means (SDs) of the anthropometric data of the participants as well as their classification and their weekly training hours.

<table>
<thead>
<tr>
<th>Participants</th>
<th>Age (years)</th>
<th>Mass (kg)</th>
<th>Height (cm)</th>
<th>Disability</th>
<th>IWBF point classification</th>
<th>Volume (hours/week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>36</td>
<td>150</td>
<td>SCI</td>
<td>1.5</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>52</td>
<td>180</td>
<td>SCI</td>
<td>1.5</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>27</td>
<td>60</td>
<td>168</td>
<td>Polio</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>32</td>
<td>68</td>
<td>168</td>
<td>Polio</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>75</td>
<td>180</td>
<td>Ortho</td>
<td>4.5</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>22</td>
<td>103</td>
<td>194</td>
<td>AB</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>24</td>
<td>68</td>
<td>175</td>
<td>AB</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Means (SD)</td>
<td>25(4)</td>
<td>66(19)</td>
<td>174(13)</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

IWBF, International Wheelchair Basketball Federation; SCI, spinal cord injury; polio, post poliomyelitis; ortho, orthopedic involvement of knee; AB, able bodied; SD, standard deviation.
(Type ZS, Friedrichshafen, Germany), producing a braking torque from 0 Nm to 4 Nm, one on each side of the roller system, which are mounted on a force sensor. The roller system was calibrated prior to the beginning of the study with a control kit for a 0, 1, 2, 3 and 4 Nm gauging range. Two incremental encoders with high resolution (3600 points per rotation) were used to measure the wheels’ instantaneous velocity. The velocity and force signals were sampled at 100 Hz, and then transposed to a NI-6024E data acquisition card (National Instrument®, Austin, TX) in a computer (Victor Technologies 386SX®).

**Testing procedure**

After a standardized warm-up and familiarization phase of 10 min (during this familiarization phase of 10 min, the participants tested the different adjustments), all of the participants performed in a random order four maximal eight-second sprints. They repeated the test according to two modes of propulsion (SYN and ASY) and two wheel cambers (9° and 15°). At the audio and visual signs given by the experimenter, the participant performed a sprint from standstill as fast as possible for eight seconds with encouragement from the experimenters. Between each sprint, a complete rest period of five minutes was imposed during which time the experimenter proceeded with the adjustments of the wheelchair’s camber angle and the ergometer. No propulsion technique was imposed on the participant, neither before nor during experimentation. Trunk movements were not restricted because no subject involved in the study used a strap during competition.

Before each sprint, the individual residual torque (Tr), due to the distortion of the tire on the rollers, and the rolling resistance of both rollers and wheelchair, were measured. For this, we used the method of Theisen et al. [15] The participants completed two or three maximal pushes on the hand-rim, and then maintained the predetermined “standard” position (the trunk leaned slightly forward with the elbows on the knees and the chin in the hands) until the wheels came to a complete stop.

**Measurements**

All of the values were recorded separately for the two wheels of the wheelchair. In accordance with the protocol of Veeger et al. [16], the first three seconds of the sprint (corresponding to the start) were not analyzed. Figure 2 is an example of velocity and power output developed during SYN and ASY sprints.

For each sprint, the following values were recorded: the mean velocity per propulsion cycle (Vm), the cycle time (Ct), the time of the propelling phase (Pt: pulling and pushing phases during which the user propels the wheels of his wheelchair: hand in contact with the wheel), as well as the relative time in a percentage of the total cycle time (Pu/Ct). The temporal parameters (Ct, Pt) were determined by the acceleration and deceleration phases of the wheels observed on the instantaneous speed curve. For ASY strategy, arm frequency (AF) was calculated by obtaining right and left arm cadences separately, taking hand-rim contact with the hand as indicator of their cadence and then by adding both values [6,9,10]. Fluctuation in the velocity profile (FPV) was the difference in maximum and minimum velocity in cycle propulsion. The total external power output developed during the push phase (Ptot) is the sum of the power developed by the participant to overcome the inertia during the push phase (Pi) and the brake power (Pb) developed to overcome the residual torque [11,13] given, respectively, by the following equations:

\[ Pi = (Ti \cdot \omega) \]
\[ Pb = (Tr \cdot \omega) \]

with Ti (Nm) defined by the torque needed to overcome the inertia, \( \omega \) (rad.s\(^{-1}\)) the angular velocity of the rollers and Tr the residual torque defined above.

**Statistical analysis**

For each parameter, the means and SDs were calculated. After ensuring that the normal distribution and the covariance homogeneity were satisfied, two-factor ANOVA for repeated measures with a 2 × 2 design (two modes of propulsion: ASY and SYN; two wheel cambers: 9° and 15°) was applied to determine the effect of the type of propulsion on the biomechanical parameters. A Bonferroni post hoc test was applied to determine the location of any significant main effects. The level of significance was set at \( p < 0.05 \). All statistical analyses were performed using Matlab® (Mathworks, Natick, MA) and Statistica software® (Statsoft, Tulsa, OK). The Pearson method was used for Vm correlation testing between modes of propulsion (ASY versus SYN).

**Results**

In Table 2, the means ±SDs Vm were between 3.1 ± 0.5 m.s\(^{-1}\) in 15°-ASY condition and 4 ± 0.4 m.s\(^{-1}\) in 9°-SYN condition. For the Ptot, the smallest was in 9°-ASY condition (120.2 ± 31.8W) and the biggest in 15°-SYN condition (274.6 ± 45.6). There was a statistical difference between the mode and the camber but no interaction between these two parameters.

As for the temporal variables (Ct, Pt, Rt, Pt/Ct and AF), no significant differences were found between camber angles (Table 2). However, there was an increase (not significant, \( p = 0.07 \)) in Pt proportional to the wheel camber.

Temporal parameters were not influenced by wheel camber but by propulsion modes. We found lower Ct and Rt values for synchronous and inversely, Pt/Ct and AF were greater for synchronous mode versus asynchronous one. The FPV is inferior to ASY (0.07 ± 0.03 and 0.10 ± 0.04) versus SYN (0.10 ± 0.02 and 0.17 ± 0.06), whatever the camber angle.

In Table 3, Pearson’s correlation coefficients between Vm in the four conditions were only statistically significant for SYN strategy between 9° and 15° (9°-SYN versus 15°-SYN) and ASY between 9° and 15° (9°-ASY versus 15°-ASY). No statistical differences were observed between 9° and 15° for ASY versus SYN condition, nor 9°-ASY versus 15°-SYN.

**Discussion**

The main purpose of the study was to investigate the SYN versus ASY mode of propulsion and their effect on sprinting performance. To the best of the author’s knowledge, no studies have focused on the impact of propulsion mode (i.e. SYN versus ASY) on wheelchair basketball sprinting. The major finding of this study is that the SYN mode compared to the ASY mode is more efficient in regard to reaching mean maximal velocity during maximal sprinting exercises. Whatever the mode of propulsion, the increase in wheelchair camber was associated with a significant increase in Ptot and a significant decrease in Vm. This is in agreement with previous studies [11,13] which have reported such results as a consequence of an increased rolling resistance on the roller ergometer.

**Synchronous versus asynchronous mode**

The greater results of this part are a statistically significant higher Vm of the SYN (between 3.5 ± 0.4 and 4.0 ± 0.4 m.s\(^{-1}\)) versus ASY (between 3.1 ± 0.5 and 3.4 ± 0.5 m.s\(^{-1}\)) mode as well as
Figure 2. Example of velocity and power output developed by a typical participant during (a) synchronous and (b) asynchronous sprint.

Table 2. Means and SDs of the measured variables: velocity (Vm), fluctuation in the velocity profile (FPV), total power (Ptot), cycle time (Ct), propelling time (Pt), recovery time (Rt) and arm frequency (AF).

<table>
<thead>
<tr>
<th>Mode</th>
<th>Camber</th>
<th>Synchronous</th>
<th>Asynchronous</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>9°</td>
<td>15°</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>9°</td>
<td>15°</td>
<td>Mod</td>
</tr>
<tr>
<td>Vm (m·s⁻¹)</td>
<td>4.0 ± 0.4</td>
<td>3.5 ± 0.4</td>
<td>3.4 ± 0.5</td>
<td>3.1 ± 0.5</td>
</tr>
<tr>
<td>FPV (m·s⁻¹)</td>
<td>0.10 ± 0.02</td>
<td>0.17 ± 0.06</td>
<td>0.07 ± 0.03</td>
<td>0.10 ± 0.04</td>
</tr>
<tr>
<td>Ptot (W)</td>
<td>163.9 ± 40.0</td>
<td>274.6 ± 45.6</td>
<td>120.2 ± 31.8</td>
<td>172.3 ± 39.5</td>
</tr>
<tr>
<td>Ct (ms)</td>
<td>413.6 ± 36.8</td>
<td>426.4 ± 28.8</td>
<td>612.9 ± 190.7</td>
<td>637.9 ± 182.3</td>
</tr>
<tr>
<td>Pt (ms)</td>
<td>145.7 ± 12.7</td>
<td>157.1 ± 9.5</td>
<td>142.1 ± 23.8</td>
<td>159.3 ± 31.5</td>
</tr>
<tr>
<td>Rt (ms)</td>
<td>267.9 ± 33.1</td>
<td>269.3 ± 26.4</td>
<td>470.7 ± 166.9</td>
<td>478.6 ± 154.4</td>
</tr>
<tr>
<td>Pt/Ct (%)</td>
<td>28.0 ± 2.4</td>
<td>26.3 ± 2.9</td>
<td>24.2 ± 3.5</td>
<td>23.7 ± 5.4</td>
</tr>
<tr>
<td>AF (pushes/min)</td>
<td>292 ± 24</td>
<td>282 ± 18</td>
<td>212 ± 59</td>
<td>202 ± 59</td>
</tr>
</tbody>
</table>

NS, non-significant differences; Mod, mode; Cam, camber; Int, interaction between mode and camber.
*p < 0.05 and ***p < 0.001.
greater push power whatever the wheel camber. Different investigations of the mode of propulsion show that physiological responses of SYN mode are more efficient than for ASY mode [5]. During submaximal propulsion, Goosey-Tolfrey and Kirk [5] suggested that the SYN mode of wheelchair propulsion was more economical than the ASY mode when AF was lower (40 pushes min$^{-1}$). In our study, with greater AF (between 202 ± 59 and 282 ± 18 pushes min$^{-1}$), synchronous mode was more efficient than asynchronous mode with regard to mean maximal velocity. This was similar to handicycling results, which Lenton et al. [6] pointed out the role of the trunk as a possible contribution for this efficiency. In fact, in handicycling, different authors [13,17–19] proposed that the beneficial effects of the SYN mode may also be caused by the implication of the larger muscle mass of the trunk, which would allow the weight of the trunk to be effectively used in propulsion. In Table 3, we have highlighted a correlation between velocity and wheel camber; however, no correlation between velocity and propulsion mode was observed. Consequently, players going faster using SYN mode are not necessarily the ones going faster using the ASY mode. Such result can be explained by a functional potential difference among wheelchair basketball players (i.e. their functional abilities depending on their disability level), especially trunk function and also on their ability to perform.

However, physiological responses in SYN or ASY mode of propulsion show contradictory results in regard to wheelchair propulsion. In fact, during submaximal push strategy tasks (SYN versus ASY), Glaser et al. [3] found significantly greater efficiencies during ASY versus SYN mode of propulsion. Lenton et al. [4] proposed that ASY propulsion allows greater continuity of the hand-rim force application, reducing fluctuations in the velocity profile and therefore, the inertial forces overcome with each stroke are reduced. Our results are in line with this hypothesis. Indeed, the FPV is inferior for ASY (0.07 ± 0.03 and 0.10 ± 0.04) versus SYN (0.10 ± 0.02 and 0.17 ± 0.06) in both camber angles.

Spatiotemporal parameters are not influenced by wheel camber but by propulsion mode. We found greater P/tCt and AF for synchronous mode versus asynchronous mode and inversely, lesser Ct and Rt values for synchronous one for which greater velocity was found. We suggest that such increases may be the result of, on one hand, a more important recovery phase between two pushes for one arm as a consequence of asymmetrical arm movement and on the other hand, by a trunk rotation resulting from this asymmetry.

**Limitations and future recommendations**

A limitation of this study concerns the use of only one standardized basketball wheelchair on a stationary ergometer. However, in accordance with previous studies focusing on wheelchair propulsion mode, no individual adjustments relative to anthropometrics of the participants were made. A standardized chair configuration eliminated influences of the chair designs/sets on the study outcomes [6]. The use of a stationary ergometer could explain why the participants had no problem keeping the front wheel parallel to the propelling direction during the ASY mode in wheelchair. One should be cautious extrapolating these data since a steering condition was not permitted. Indeed, steering is suggested to involve trunk function in a different way. A second limitation of this study is the choice to not include the first three seconds of each sprint session into the analysis, according to the protocol of Veeger et al. [16]. But, for some wheelchair basketball players, it can be seen that, after the third second of sprint, stationary velocity is neither achieved in SYN condition nor in ASY condition (Figure 1). Therefore, the parameters Vm and Ptot can be affected by this transitory period during which the user is reaching his maximal velocity. At last, future studies assessing a larger sample and considering athlete classification are needed in the field with individual wheelchair.

**Conclusion**

Under the current experimental conditions of this study, we have shown that SYN mode leads to better performance than ASY mode, in terms of maximal propulsion velocity.

However, the fluctuation in the velocity profile is inferior for ASY versus SYN for both the camber angles. Therefore, ASY propulsion allows greater continuity of the hand-rim force application, reducing fluctuations in the velocity profile. Clearly, future experiments need to be performed in the field with a larger sample athlete classification.

**Declaration of interest**

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

**References**


