A Preliminary Investigation into the Factors Impacting Tyre Failure in Wheelchair Basketball

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Abstract: Wheelchair sports are increasingly gaining popularity amongst athletes and spectators alike. This report outlines work carried out investigating the physical influences on the equipment used for Wheelchair Basketball. The preliminary experimental study explores the degradation of wheelchair tyres through the analysis of temperature, inflation pressure, acceleration, gameplay, individual playstyle, and strategy. With the aid of pressure monitoring and inertial measurement technology the study investigated the impact of player action on the wheelchairs. The experimental study was carried out in two phases employing the first phase of testing to provide the basis of the second phase. Through the first phase it was observed that the different temperature modalities did not have a significant impact on the degradation. The second phase focused on pressure observations and inertial sensor data paired with video. Through this process, the effect of player action was observed to have the greatest impact on the tyre degradation. Aggressive playstyles characterised by heavy impacts, and sharp decelerations were shown to play a significant role in reducing equipment reliability.

1 INTRODUCTION

The physical benefits of exercise are well investigated for able-bodied individuals, enhanced psychological benefits for those living with disabilities may be an additional pro that still requires further enquiry. Improvements in general quality of life and an opportunity to positively reinterpret their abilities and roles in society being key contributors to maintaining good mental health (Bergamini, et al., 2015). Wheelchair sports are becoming increasingly popular for athletes with disabilities and amongst spectators. Wheelchair Basketball (WB) is the most developed sport in relation to the number of participants, understanding of the rules by the audience, organisation, standardisation, and quality of training (Seron, de Carvalho, & Greguol, 2019). Under the rules of WB, wheelchairs are considered a part of the player themselves (IWBF Executive Council, 2020). Athletes, therefore, rely on their wheelchairs functioning in perfect condition to be able to train and deliver high level performances. Tyre reliability and the logistical demands created to meet the challenge presented by critical tyre failure, have become a major factor in diminishing performance. Alongside this, the impact on gameplay and strategy also hinders participation levels from prospective players, especially in competitions that require interstate or international travel.

This paper describes a preliminary study into the sport of WB and the physical factors impacting the degradation of the equipment used. The study investigates the factors impacting critical failure of tyres in WB, by experimentally determining the influence of phenomenon such as friction, internal tyre pressure, and in-game collisions. The study aims to provide insight into the causation of tyre failures, and lay the groundwork for future enquiry. The small study attempts to break new ground with limited resources and testing opportunities, to undertake the initial research required to provide justification for larger and more in-depth investigations in the future.

2 BACKGROUND

Investigations into WB and other wheelchair sports have primarily been targeted at performance enhancement, and the impact of the equipment on the physiology of the athlete (Seron, de Carvalho, & Greguol, 2019). The existing work appears scarce in relation to the reliability of the wheelchairs. The review process carried out, covered investigations

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into the physiological impact of WB, tyre types, external and internal physical conditions, alongside the use of technology to develop an improved insight into WB.

Camber angle has been defined as the angle of the wheels with respect to the vertical axis, such that the distance between the top points of the wheels is less than that of the bottom points (Mason B. S., Van der Woude, de Groot, & Goosey-Tolfrey, 2011). Sports wheelchairs have large cambered rear wheels which by expanding the wheelbase area provide increased stability. Tubular pneumatic tyres are a popular choice for athletes since these tyres are enclosed within the rim wall of the wheels enabling higher inflation pressure (i.e., 125 psi) and are believed to be less prone to punctures (Brandt, 1993). A study investigating the influence of various tyre configurations, highlighted the importance of the tyre type and the internal pressure (Mason, Lemstra, van der Woude, Vegter, & Goosey-Tolfrey, 2015). The study found that the preferred pneumatic tyres reduced the physiological demand, compared to failure proof solid tyres. The same study highlighted the importance of minimising rolling resistance and concluded that inflation pressure had a significant impact on performance, but there existed a point beyond which the pressure becomes too high to provide athletes with enough grip to perform.

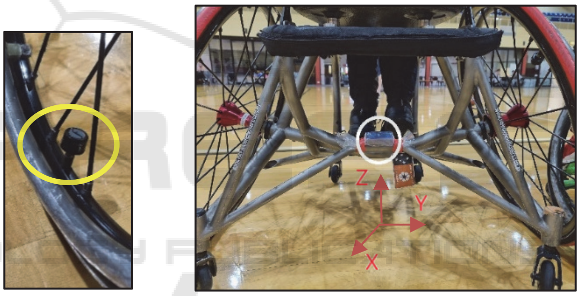
Operating conditions and workload experienced by the wheelchairs play a significant role in the failure of tyres. The literature reports that operating conditions such as under- or over-inflation, excess weight, and improper wheel orientation are major contributing factors to early or unexpected tyre failure (Evans, 2002). A study looking into the workload on athletes estimated that players travelled up to 5 kms per game and approximated 64% of game time spent in propulsion (Coutts, 1992). Court sports, unlike racing require braking, sharp changes in direction, striking, catching, and contact alongside acceleration and speed maintenance. Such investigations provide support for the use of pneumatic tyres for WB.

Fuss (2012) discussed the validity of gyroscopes in accurately ascertaining performance metrics in wheelchair sports through experimentally and empirically evidenced knowledge gathered over a 7-year period. Shepherd et al. (2018) through an extensive review process highlighted the efficacy of IMUs for use in wheelchair court sports, while recognising algorithm and hardware barriers in widespread adoption. The impact of the operant conditions on the reliability of the playing equipment, however, remains largely unexplored.

2.1 Instrumentation

A temperature gun (Fluke Corporation) and pressure gauge (BBB Digital Pressure Gauge) were employed for non-invasive measurement of tyre temperature and inflation pressure. The Fobo Bike 2 sensors (Fobo Tyre) monitor tyre pressure and temperature in real time, and provide real time tracking through Bluetooth connectivity, and generate data logs (Boada, Lazaro, Villarino, Gil-Dolcet, & Girbau, 2021). The pressure/temperature sensors attach on to the tyre valves (Figure 1(a)) with minimal interaction with the athletes and constantly monitor the internal operating conditions of the tyre.

In-house IMU sensors (Espinosa, Shepherd, Thiel, & Worsey, 2019), 55×30×13 mm and 23 gms, comprising a 16g triaxial accelerometer, ±2000°/s triaxial gyroscope, ±7 Gauss triaxial magnetometer, and an LED added for video synchronisation, were used in this study. The sampling rate was set to 250 Hz. The sensors have 2.4 GHz wireless connectivity and an SD card for local data storage.



(a) (b)

Figure 1: (a) Fobo Bike 2 sensor attached to valve (b) SABEL Sense attachment location to wheelchairs (circled) with axis orientation.

3 METHODOLOGY

The investigative process consisted of physical testing divided into two phases. The first phase examined the effect of temperature and pressure on the tyres in training and games, while the second phase examined the effect of player actions and the impact on the tyres in match like situations. The results obtained from the first phase were used to inform the testing procedure for the second phase, where the IMU and video files were synchronised to analyse shortlisted events from the in-game collisions observed.

3.1 Participants

Overlapping sets of participants formed the groups engaged for the purposes of this investigation. Preliminary testing was carried out with 22 wheelchair athletes of varying classification (Mean (M)=2.8, Standard Deviation (SD)=1.4) and experience levels. Final stage testing was carried out with 7 individuals (M=2.8, SD=1.0). These individuals were selected based on player quality, and classification. Classification was used to form testing categories, following suggestions supporting a restructure of the classification system (Molik, Laskin, Kosmol, Skucas, & Bida, 2010). All final testing phase participants provided written consent and were given necessary information about the research and methods used. All investigative tasks were carried out following complete Ethics approval obtained from the Human Research Ethics Committee at Griffith University (GU Ref no. 2021/917).

3.2 Testing

3.2.1 Phase 1

Phase 1 was carried out at six training sessions and a friendly tournament. Tyre and court surface temperatures were recorded at the start of trainings, at the halfway mark, and at the end of each session. Tyre inflation pressures were recorded at one training session at the start and the end. The ambient temperature was recorded at the start of every training.

Testing at the friendly tournament focussed on 10 participants (M=2.8, SD=1.2) pre-selected by coaches from within the preliminary testing group. The tournament took place at the Boondall Entertainment Centre's (Brisbane, Australia) basketball facilities with the participants spread out over 5 distinct teams created for the purposes of the tournament comprising athletes of varying WB ability and experience. Tyre temperatures were recorded for 7 games with measurements being made pre-game and at the conclusion of each quarter. Pressure measurements were made for 4 participants over the course of 3 games with readings being taken pre-game, at half-time, and the end of the game. External ambient and court surface temperatures were recorded at the start of each game.

3.2.1 Phase 2

Phase 2 targeted inflation pressure, the influence of in-game manoeuvres, and collisions using the TPMS and IMUs. The variance displayed was tracked first at a 2-hour weekly training session, similar to those in phase 1, and a specialised training camp. The participants of the study were informed of the sensors capabilities and were present for the process of fitting each sensor onto their respective wheelchairs. For all testing sessions, 12 TPMS sensors were connected via Bluetooth to the primary investigator's smartphone.

At the training camp, two sessions were monitored over two consecutive days. These sessions were run with the goal of simulating match scenarios. The first session employed only the TPMS sensors and served to finalise justification for the additional application of IMUs. During the second session a single IMU was attached to the wheelchair of each participant, to measure impact forces. The IMUs were synced to video recordings to enable correlation of activities with the IMU data.

3.3 Data Extraction and Analysis

The data from phase 1 was analysed to uncover early trends and streamline data collection methodology. The temperature and pressure mean, standard deviation, variance and correlation values were calculated for all participants' tyres. From phase 2, the data collected was used to build temperature and pressure profiles matched to the in-training IMU data. These profiles were employed to keep track of the number and intensity of direct impacts to the wheelchairs, and to correlate any sharp changes in the pressure or temperature. Plots for player classification categories were created to visualise differences in player preferences and the impact of classification on the internal physical conditions of the tyres. The data spread observed for the athlete was graphically represented using the participants mean values as the calibration point, with reference to which a new data set was created to display the variation of each point from the mean. Using box and whisker plots to determine true outlier values from the TPMS error range, the relevant IMU data was estimated. Which was then analysed to uncover the impact of player action associated with the outliers.

4 RESULTS

4.1 Phase 1

The mean ambient temperature during the sessions was observed to be 25.0±1.9 °C. The ambient and court temperatures displayed poor correlation (r=0.313) with only 9.77% variance in court temperatures. This indicated that the ambient conditions had a small effect on the court surface, likely due to the sessions being held in indoor facilities with air conditioning. A larger effect would be expected in outdoor testing.

The court surface temperature showed a negative trend over the course of testing, as the courts cooled down from the start to the end. The mean temperatures at the different stages reflected this trend with the start, 27.8±1.85C°, half-way, 27.4±1.74C°, and end, 27.16±1.46C°. This reduction in court temperature over the duration of testing sessions indicated that the heat dissipation due to the friction between the tyres and surface was not large enough to cause the surface temperature to increase.

During testing carried out at games, a similar trend was observed in the change observed between quarters. The mean change observed for all participants was -0.14±0.39°C. The correlation (Figure 2) between the court and tyre temperatures displayed a strong positive relation at the start of games, but a weak correlation (r^2=0.0104) for readings taken post game. This was indicative that game activities had a greater impact on tyre temperatures as opposed to the court temperature.

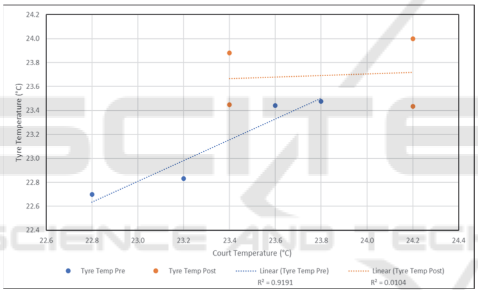


Figure 2: Tyre Temperatures VS Court Surface Temperatures during Games.

Pressure readings taken during a training session showed an average reduction of 16.5±1.96 kPa, with a mean starting tyre pressure of 524.1±68.5 kPa. Pressure measurements taken on the game day also displayed a reduction with a mean of 186.1±100.3 kPa, with participants using an average starting pressure of 624.9±20.9 kPa. The large difference between the starting pressures observed showed that the athletes preferred to play games with higher tyre pressure than trainings. This implies a greater attention to detail with regards to wheelchair setup exhibited by athletes for games. While the mass of the chair is constant the mass of the athlete is variable, hence each athlete inflates their tyres to self-selected pressures to ensure proper tread contact and peak performance, resulting in different athletes having different starting tyre pressures. The larger reduction in tyre pressure was indicative that in-game activities had a greater impact on tyre pressure as opposed to training activities. The trends observed in temperature and pressure over the preliminary testing phase indicated a non-significant impact on temperature but a significant impact on inflation pressure due to WB activities.

4.2 Phase 2

During the weekly training session used for the final phase a max pressure difference of 12 kPa was observed in one participant, with an average change of 7.17±3.01 kPa. No significant impact of varying starting pressures was observed across the participants. Nine of the 12 tyres observed showed a positive trend, displaying a small average increase in pressure over the course of the training. The pressures were observed to peak before the halfway mark where max effort was put out by the athletes before stabilising for the second half of training.

Temperature measurements followed trends similar to those observed in the preliminary phase, with tyres possessing higher temperatures at the start of training, following the court temperature and then going through a gradual reduction during the session. A max deviation of 3°C and a mean of 1.58±0.99°C was observed.

Over the first session at the training camp a max individual change of 7 kPa, with a mean pressure deviation of 4.08±1.4 kPa was observed. The shorter observation time was seen as a possible cause for the reduced deviation. The large standard deviation for the weekly training was seen as an indication of the impact of the individual athlete's playstyle and preferred equipment setup. Unlike the regular training testing, all pressure profiles exhibited a negative curve. This observation aligned with expectations for the training camp, with more uniform player effort and care for equipment exhibited by the athletes.

Temperature readings recorded during the first session displayed a mean differential of 1.17±0.39°C. With a maximum temperature drop of 2°C, the profiles for all participants displayed a small negative coefficient in line with observations earlier findings.

The data gathered at the second session of the training camp gave a mean pressure differential of 8.00±3.6 kPa, with a max difference of 13 kPa. Pressure profiles for all participants were observed to have a positive coefficient. This positive relationship was indicative of the impact of higher intensity training with greater workload on the equipment in match-like scenarios. The larger change also pointed towards the likelihood of greater tyre wear occurring in match situations as opposed to trainings.

Temperature profiles for 5 out of 6 participants exhibited a negative profile, however no participant finished the session with tyre temperatures higher than those recorded at the start. With the overall peak temperature at the start of training, temperatures were observed to reduce in the first half of the session with a second peak observed in the second half of the session which corresponded to full court practice matches being played. A maximum deviation of 4°C, and a mean deviation of 3.58±0.67°C was observed for the session. The larger deviation when compared to the regular training and the first session of the camp provided further evidence that match scenarios exerted greater load on the tyres.

4.2.1 Classification based Results

Three categories, low, middle, and high, were created based of the participant pool to organise the data based on WB player classification system. The categories also served to provide insight into the differences in impact of playstyles of athletes with varying abilities.

The low category participant displayed a negative coefficient for the left tyre but a positive coefficient for the right. Over the course of the training session both tyres initially gained pressure sharply and then gradually lost pressure over the later three quarters of the session. Temperature readings did not follow a similar trajectory, but instead displayed a sharp decrease followed by a slight increase and stabilisation. A mean pressure variation of 5.5±3.5 kPa and a mean temperature change of 2.0±1.4°C was observed.

The outlier values seen in the box plots (Figure 3) indicated the impact of training, resulting in greater variations than those predicted based on the preliminary testing. The outlier on the left tire corresponded to a pressure value of 602 kPa observed at the start of training. The outliers on the right tyre corresponded to initial inflation pressure or were within the error range of the instrumentation.

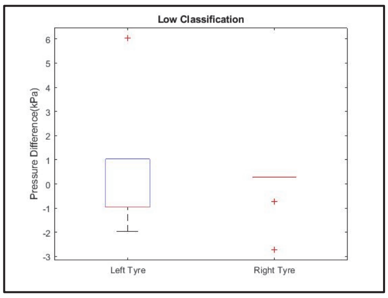


Figure 3: Low Classification Participant Pressure Variance Left and Right Tyres.

All participants of the middle category displayed a negative coefficient for their respective pressure profiles. The average maximum pressure observed over session 1 was 592.6±101.6 kPa and session 2 was 564.8±89.2 kPa. The higher pressure observed during session 1 was due to greater variation in the initial pressure preferences of the participants, reflected in the larger standard deviation.

Maximum temperature deviation observed during session 2 was 4°C, which exceeded the deviation observed in session 1 (2°C). The temperature profiles from both sessions followed the expected trends from the findings in the preliminary phase.

Middle classification participants displayed a total of 5 outliers (Figure 4), an incidence rate lower (62.5%) to that observed for the low classification category. However, the variance observed was larger, with the more data exceeding the ±2 kPa error range. The negative outlier for participant 5 displayed a pressure difference of -2.3881 kPa with a corresponding true pressure value of 431 kPa. The significantly larger occurrence rate of outliers for right tyres as opposed to left (×4) displayed a developing trend in playstyle and player habits.

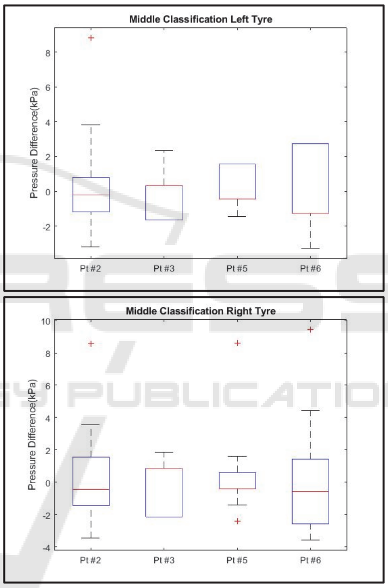


Figure 4: Middle Classification Participants Pressure Variance Left (top) and Right (bottom) Tyres at Training Camp Session 2.

The high category participants displayed negative coefficients for their pressure profiles for session 1, but a positive coefficient for session 2. The average maximum pressure observed over session 1 was 496.3±105.2 kPa and session 2 was 533.8±106.8 kPa. The greater pressure in session 2 was attributed to player preferences for higher initial inflation pressure for match scenarios.

Session 2 observed a larger temperature deviation compared to session 1. The differences in magnitude were like those observed for the Middle category. Session 1 observed an initial increase to the maximum observed temperature of 23°C followed by a stepwise decrease over the course of training.

Session 2 started with a higher temperature, 26°C, and then exhibited a sharp reduction to the minimum temperature 22°C, followed by a slight increase.

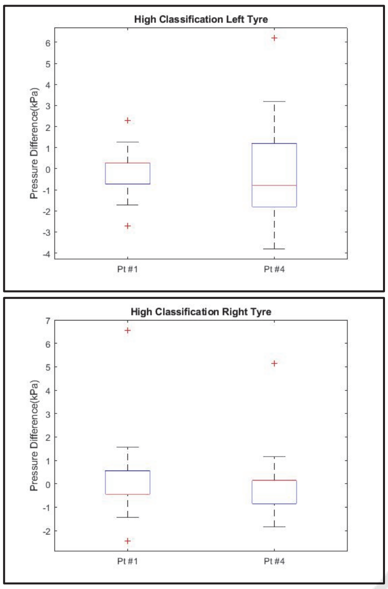


Figure 5: High Classification Participants Pressure Variance Left (top) and Right (bottom) Tyres at Training Camp session 2.

High classification participants displayed a high rate of outlier occurrence (150%) and variance sizes exceeding the accepted error range (Figure 5). With increased trunk control and ability, it was observed at trainings that high classification athletes were better positioned to place themselves and their chairs in extreme situations to extract the best possible performance. Both negative outliers observed for participant 1 corresponded to the chosen initial inflation pressure by the participant. The largest outlier, 6.5556 kPa, corresponded to a true pressure of 484 kPa displaying an instantaneous change of 7 kPa, during a 3v3 half-court drill designed to simulate condensed activity but lowered intensity match scenario.

4.2.2 Outliers

Of all the outliers observed, two were deemed to be of particular interest. Participant 6 displayed the largest pressure differential of 9.4351 kPa from the mean with a corresponding true pressure of 568 kPa. The instantaneous pressure change was reported to be 10 kPa. During a half court scrimmage, participant 2 displayed a sharp increase of 4 kPa. The elevated pressure was sustained for a period of 15 mins followed by a drop of 2 kPa.

From the IMU data observed for these two outliers along with video analysis, participant 2 (Figure 6) was observed to move in a short arc on the court ending in a sudden stop with the athlete facing 90° out of phase from the direction of initial movement. The change in direction was represented clearly in the gyroscopic data with large, elongated peaks displayed in the z and y axis of the data. These peaks were followed closely with accelerometer peaks along the y and z axes, displaying the instantaneous deceleration. The max acceleration observed was 15.9995 g along the y, and the minimum acceleration observed was along the z-axis at -14.7329 g. As the IMU was placed such that the y-axis ran parallel to the player surface and in line with the wheelchair axel representing forces experienced from either side of the athlete, the acceleration can be seen to cause a skidding motion increasing tyre deformation and in-turn the likelihood of failure.

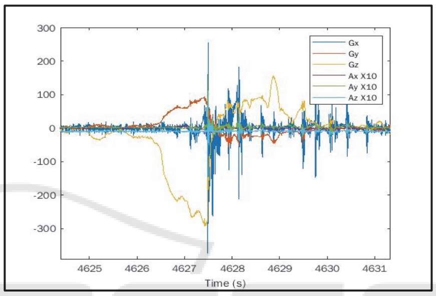


Figure 6: Participant 2 Outlier IMU Curve.

Participant 6's outlier (Figure 7) was not captured on video. The gyroscopic data displays very little change through the incident. The triaxial system displays an absolute maximum change not exceeding 200°/s, indicating that no large change in direction occurred. However, the sharp peaks from the gyroscope and the coinciding peaks from the accelerometer hint that the athlete came to a sudden stop or was impacted by another athlete. A maximum acceleration of 12.98 g was observed along the z-axis, closely followed by a slightly lower y max. Minimum acceleration was seen along the x-axis indicating that the force was imparted from the front of the participant.

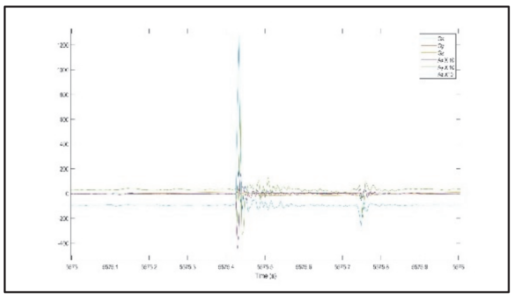


Figure 7: Participant 6 Outlier IMU Curve.

5 DISCUSSION AND CONCLUSION

Investigations into the various temperature modalities provided evidence of the minimal impact of ambient air temperature. Further, while it was observed that court surface temperatures have a strong relationship with initial tyre temperatures, there was little impact on the temperature variations displayed over the course of testing. The small negative change observed in internal and tyre material temperature indicated that the effort exerted by the players and the interaction of the tyres with the court possessed a significant but uniform impact on tyre wear. The uniform negative trend eliminated temperature as one of the major physical influences, leading to greater emphasis on the influence of variable inflation pressure as a source of the failures. An inconsistency was observed in the initial inflation pressures employed by the participants, as some were particular about initial pressures prior to games to ensure performance quality, and comfort. The inconsistency in initial pressure, however, was not observed to have a significant impact on the individual variations in pressure. The overall trend of pressure reduction confirmed the expected material interaction between the tyres and the surface, with localised sharp changes pointing towards the impact of gameplay.

Through the evidence gathered in the final testing phase the importance of individual playstyle, physical classification, and tendencies was highlighted. The accelerometer and gyroscope data provided evidence of the high g-forces experienced by the athletes and the equipment drawing attention to the workload placed on both.

Over the course of the preliminary and final phase of testing the greater impact on equipment during the match scenarios as opposed to regular training sessions was confirmed. Through preliminary findings it was suspected that player actions that caused direct collisions to tyres or made the wheelchairs move in unpredictable trajectories, such as dragging sideways or tipping on to one wheel, resulted in large forces being experienced and likely to be a contributing factor in accelerated tyre degradation. Insignificant differences were observed for the pressure variations between classification categories indicating a small influence of the individual player classification on the pressure variation. Anecdotal evidence gathered in conversation with athletes and coaches indicated that higher classification athletes and those with aggressive playstyles experienced more tyre failures. Through the combined analysis of participant pressure profiles, IMU data, and match simulation video recordings it was confirmed that athlete actions held a large influence on tyre degradation and failure. It was also noted that offence more than defence, and athlete hand preferences effected the rate of failure for individual tyres.

The outcomes from the study provide evidence from varying tyre pressures to back anecdotal knowledge of the tyre degradation patterns observed. The findings allow athletes and coaches to make better in-game and training decisions. Through the multi-phased experimental methodology employed, the investigators were able to build an argument for increased enquiry into WB and other para sport equipment reliability.

Several setbacks over the course of the research period reduced the potential of the study. As the focus of the study was to investigate the effects of player actions on the physical properties, emphasis was laid on testing to occur in real world environments. The present study was unable to capture competitive match data, focus on gathering such evidence would be key to further the understanding of WB physics. CAD models could be employed to simulate testing and establish reference values of failure to inform future work. The TPMS technology employed was designed for non-scientific purposes, possessed low resolution, and did not possess a standardised sample rate. The use of more specialised sensors would allow for better analysis and produce more informative results. An increased number of SABEL Sense IMUs employed on the wheels (following (Shepherd, Wada, Rowlands, & James, 2016)) would allow for measuring impacts in additional planes.

The study laid the groundwork for further targeted investigations into inflation pressure and temperature in competitive match situations. The influence of match scenarios as opposed to training on the degradation rate of the equipment forms the core of the experimental study. The results discussed expand the understanding of WB gameplay, and leave room for future enquiry in to the sport and other parasport modalities.

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