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The impact of trunk impairment on performance-determining activities in wheelchair rugby

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In Paralympic sport, classification of impairment is needed to prevent a one-sided and predictable outcome of competition, in which the least impaired athlete has the best chance to win. To develop evidence-based classification in wheelchair rugby, the impact of trunk impairment, measured by the Trunk Impairment Classification (TIC), on performance-determining activities was assessed. Arm impairment was analyzed as a covariant. Fifty-five athletes, 21 with TIC score 0, 13 with TIC score 0.5, 11 with TIC score 1.0, and 10 with TIC score 1.5 performed standardized sport-specific activities. A multiple step forward regression analysis was performed for all activities to assess the relative impact of trunk and arm impairment on performance. Trunk impairment was the most important factor for tilting the chair and acceleration in the first 2 m. The explained variance of the performance by trunk and arm impairment ranged from 23% for acceleration in the first meter, to 37% for sprint momentum, the tilt test left, and the time to cover 3 and 4 m. This study shows that athletes with limited trunk impairment are more proficient in wheelchair rugby than athletes with severe trunk impairment.

The Paralympic Games are the world's third-largest sporting event, and continue to be fast growing (International Paralympic Committee Annual Report, 2012). A challenge to the appeal of Paralympic sport is the threat of a one-sided and predictable outcome in competitions, in which the least impaired athletes have the best chance of winning. From the very first start of Paralympic sport, athletes were classified or grouped for competition to prevent one-sided and predictable outcomes (Tweedy & Howe, 2011). Initially, classification systems were based on the expert opinion of volunteer classifiers. With the growth of the Paralympic Movement and the increasing professionalism of Paralympic sport, it became apparent that classification based on expert opinion was not sufficient. In 2007, the International Paralympic Committee published the *IPC Classification Code and International Standards*, which provided a structure for classification principles for all Paralympic sports (IPC Classification Code and International standards, 2007). According to the code, International Federations are responsible for developing evidence-based classification through research. The 2009 IPC position stand provided guidelines on how to achieve evidence-based classification systems (Tweedy & Vanlandewijck, 2009). These guidelines prescribed three research steps: (a) to develop objective, reliable measures of the severity of eligible impairment types, (b) to develop objective and reliable measures of sport-specific activity limitation, and (c) to investigate the relative strength of the association between severity of impairment and activity limitation, in a large representative sample.

Based on these guidelines for evidence-based classification, a new Trunk Impairment Classification system (TIC) has been developed in wheelchair rugby (International Wheelchair Rugby Federation Classification Manual, 3rd edition revised, 2015). Wheelchair rugby is an indoor team sport played on a basketball size court. Athletes in manual wheelchairs compete in teams of four to carry the ball across the goal line of the opposing team. Contact between wheelchairs is permitted and encouraged as an integral part of the sport. Athletes use their chair to block and hold opponents. The sport was developed for athletes with tetraplegia due to spinal cord injury and health conditions leading to similar impairment (Orr & Malone, 2010; Malone et al., 2011). Both trunk and arm impairment are evaluated in the sport-specific classification system. However in this research, we will focus on trunk impairment, measured by the newly developed TIC. The reliability of the TIC and the validity with regard to biomechanical trunk impairment have been established (Step 1 in evidence-based classification) (Altmann et al., 2013, 2015). The second and the third steps in research for evidence-based classification need to be taken.

An important factor, which complicates the second step in evidence-based classification research – the development of valid measures of activity limitation, is the absence of a single evidence-based test for activities to determine the level of performance in (wheelchair) team sport (Yilla & Sherill, 1998; Vanlandewijck et al., 2001; Baker & Newton, 2008; Ali, 2011; Rice et al., 2011). It is recognized that there is no gold standard for the level of performance in wheelchair team sport (Yilla & Sherill, 1998; de Groot et al., 2012). In some wheelchair basketball research, the number of goals during a game is used as a gold standard measure of performance (Cavedon et al., 2015). An alternative is based on the ranking of individual athletes by athletes or coaches (Yilla & Sherill, 1998; Gabbett et al., 2007; De Groot et al., 2012), or on the ranking of the team for which the athlete is playing (Baker & Newton, 2008; de Groot et al., 2012; Rhodes et al., 2015). Using these methods for validating tests that measure performance in Paralympic sports is complicated, because the number of athletes in Paralympic sports is small and the numbers of athletes per sport class based on impairment type(s) are even smaller (Yilla & Sherill, 1998; Altmann et al., 2014; Cavedon et al., 2015). This results in a small number of athletes per sports class, which limits statistics to validate sport-specific tests based on ranking in Paralympic sports.

Only a few studies have been performed to define which wheelchair activities determine performance in wheelchair team sports. Some studies used structured interviews, with coaches, experts, and/ or athletes (Yilla & Sherill, 1998; Mason et al., 2010; de Groot et al., 2012). Other studies assessed the correlation between standardized activities and the ranking of the team (de Groot et al., 2012; Rhodes et al., 2015) or the correlation between standardized activities and goal effectiveness in a wheelchair basketball game (Cavedon et al., 2015). In almost all studies, sprinting and maneuverability were identified as performance-determining activities in wheelchair court sports (Yilla & Sherill, 1998; de Groot et al., 2012; Cavedon et al., 2015; Rhodes et al., 2015). In addition, in literature mainly based on expert opinion such as sport handbooks, sprinting and maneuverability were also mentioned as extremely important. Mentioned to a lesser extent were activities such as hitting (Yilla & Sherill, 1998; Orr & Malone, 2010), initial acceleration (Mason et al., 2010), and tilting or hopping the chair (Frogley, 2010). Hitting is defined as a maneuver in which the athlete uses his chair to make contact with and stop an opponent's chair (Orr & Malone, 2010). Tilting is defined as a quick body movement while strapped to the wheelchair, resulting in the wheelchair tipping over to one side with one large wheel off the floor (Frogley, 2010).

The purpose of this study was to assess the relationship of the TIC with wheelchair activities that determine performance in wheelchair rugby. Because the performance in wheelchair rugby is not only determined by trunk impairment but also by arm impairment, arm impairment will be included as a covariant. Based on the literature and expert opinions, four activities were hypothesized to be highly affected by trunk impairment: maneuverability, initial acceleration, tilting the chair, and hitting. The largest impact of arm impairment was expected in a 10-m sprint (Orr & Malone, 2010; Malone et al., 2011). Therefore, it was hypothesized that a 10-m sprint, although a performance-determining activity, would be minimally affected by trunk impairment.

Material and methods

Participants

Fifty-five athletes participated in this study and were recruited from wheelchair rugby and wheelchair basketball teams taking part in the 2011 national competition in the Netherlands and Belgium. Twenty-six wheelchair rugby athletes and 26 wheelchair basketball athletes and three athletes playing both sports participated. The athletes had the following health conditions, SCI (29, of whom two also had a transfemoral amputation), neuromuscular disease (nine), cerebral palsy (four), skeletal dysplasia (three), amputations (three), arthrosis of the joints of the legs (three), spina bifida (three), and one athlete had coordination impairment of the legs of unknown origin. The study was approved by the Medical Ethical Committee for the regions Arnhem and Nijmegen (registration number 2011/378). All athletes signed an informed consent. Date of birth, body height, and body weight were noted. The characteristics of the personal equipment used by each athlete (wheel size, sitting height, seat angle, backrest height, and camber angle of the wheel of the customized rugby wheelchair and the use of strapping around the belly and the hips) were also recorded. Athletes were at least 18 years of age (mean: 34, SD: 10) and had a minimum of 1-year experience in either wheelchair basketball or wheelchair rugby competition at a national or an international level. None of the athletes had pressure sores on the sitting surface. Athletes were classified by an experienced international classifier (VA) using the TIC (0, 0.5, 1.0, or 1.5, the lowest score indicating the most severe trunk impairment). Furthermore, arm impairment was categorized into two groups: "severe arm impairment" defined as Manual Muscle Testing (Hislop & Montgomery, 2007) grade 3 or less in any of the muscles around the shoulder, elbow, and wrist; "minimum to no arm impairment" defined as Manual Muscle Testing grades 4–5 for all muscles around the shoulder, elbow, and wrist.

Research design

A cross-sectional design was used. Athletes performed four tests in one session: (a) a 10-m sprint test, (b) a turn test, (c) a tilt test, and (d) a maximal initial acceleration test. Athletes performed three trials per test. All tests were done in a sports hall on a wooden surface wheelchair rugby court. Athletes were allowed to use their own equipment, including gloves, strapping, and custom-made wheelchair rugby chair for all tests with the exception of the tilt test, for which their every day chair was used. For each test, two athletes were tested alternately per trial with a short break after each test to ensure fatigue did not influence the results. Moreover, testing two athletes at the same time introduced a competitive element, which encouraged the athletes to maximize their effort. Tests were performed in a random order across sets of athletes to correct for sequence effects. Athletes were allowed to practice each test once to familiarize themselves with the test. Each trial was started when the participant indicated readiness to perform.

Sprint test

A distance of 10 m was chosen for the sprint test, rather than 40 m used in performance studies in the able body rugby league (Baker & Newton, 2008), because the length of the wheelchair rugby court measures approximately one-fourth of a rugby league playing field (Orr & Malone, 2010). Two sets of infrared sensors (2.50 m apart) were placed at the start and at 10 m from the start. Athletes performed a maximal effort linear sprint from standstill. They were instructed to sprint as fast as they could until a few meters after passing the second sensor. The time between the front of the chair passing the first sensor and then passing the second sensor was automatically measured and stored on a laptop using Matlab (Version 7.2.0; R2006a; The Mathworks, Inc, Natick, Massachusetts, USA).

Turn test

The same set of infrared sensors and the same starting position used in the sprint test were utilized. However, after the second sensor, a semi-circle with radius 1.25 m was added to force athletes to turn 180°. The radius was approximately 1.5 times the average width between the large wheels of the wheelchair. After pilot testing, this radius was determined as the narrowest curve that could be completed accurately by all athletes without allowing them to cut the corners. The margins of the turn were marked with five poles (1.60 m height) and a cone was placed in the center of the semi-circle, positioned just behind the second sensor. The setup is shown in Fig. 1.

Athletes were instructed to perform a maximum sprint, make the turn as fast as possible and sprint back to pass the start again. They had to perform three trials turning to the right and three to the left. If they touched either the poles or the cone, the trial was recorded as a failure. A maximum of one extra trial was allowed in the event of a failure. Failed trials were excluded from analysis. The outcome measure was the time between passing the first sensor and then passing the first sensor again with the front of the chair. These times were automatically measured and stored on a laptop using Matlab (Version 7.2.0; R2006a, The Mathworks, Inc).

Tilt test

For the tilt test, athletes were seated in their everyday chair to reduce the impact of seating position and the camber axis of the wheels on tilting as much as possible (Frogley, 2010; Mason et al., 2010, 2012; Orr & Malone, 2010; Rice et al., 2011). There is considerable variation in the camber axis and

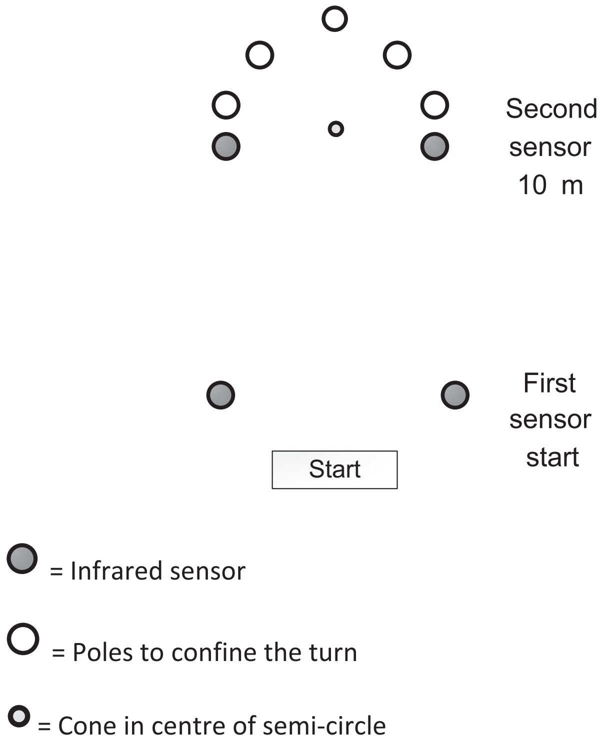

Fig. 1. Setup of the turn test.

the angle of the front edge relative to the rear edge of the seat (seat dump) in a rugby wheelchair, compared to an everyday chair. The camber axis of the wheels of an everyday chair generally is 2° with a seat angle close to 0° (limited to no seat dump). The thighs of the athletes were tightly strapped to the chair at the hips and the knees using a standardized strap. One of the rear wheels of the chair was fixed using triangular bumpers on the rear and the front of the wheel. On the side of the fixed wheel, a thick foam mattress was positioned for safety. Athletes were instructed to cross their arms in front of their chest. They were directed to try and lift the non-fixed wheel from the floor using their legs and trunk, and hold this tilted position. They were not allowed to move their arms or trunk outside the base of the wheelchair to enhance tilting. Three trials were done lifting the left wheel and three lifting the right wheel. The height of the tilt was measured using a tape measure attached with a pulley system on the axis of the wheel on the side that was lifted. The initial height (H0) and the maximum height per trial (H1) were recorded in mm by the researcher (see Fig. 2).

Acceleration test

Athletes were instructed to maximally accelerate from standstill, starting at the baseline of the court. Upon reaching maximum velocity, they had to maintain their maximum velocity for 3–5 m. Subsequently, they were allowed to decelerate using the remaining available court space. Displacement of the wheelchair was continuously measured by means of the Cheetah LMT attached to the wheelchair (AMR Sports, Chirn Park, Queensland, Australia). Displacement and time were measured with 10-mm intervals. Acceleration was derived from these data by the second derivative of displacement with respect to time. The attempt with the highest maximum acceleration was used for analysis. Outcome measures consisted of the times to cover 1, 2, 3, and 4 m.

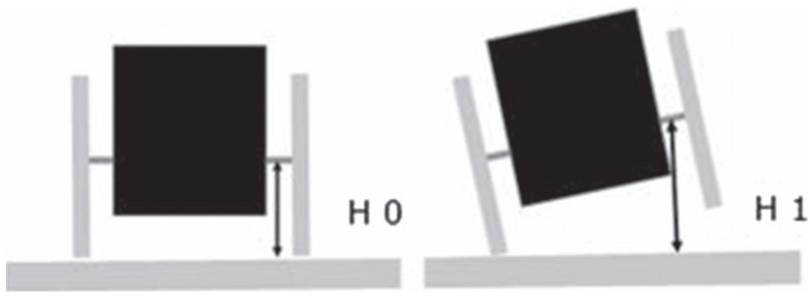

Fig. 2. Measurement of the height of the tilt in the tilt test.

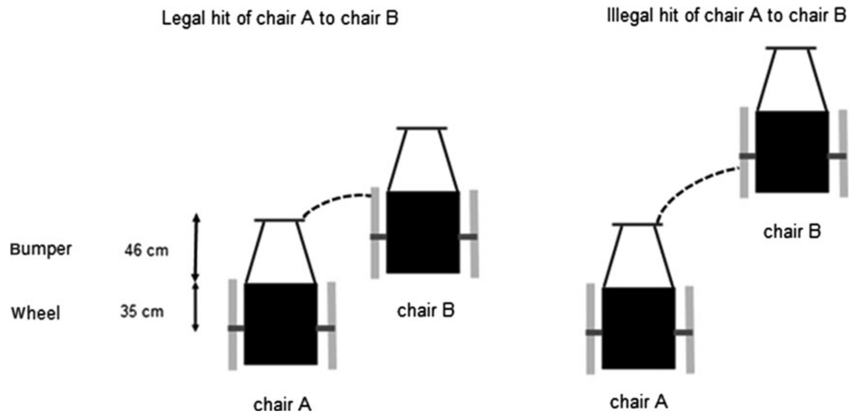

Fig. 3. Example of a legal and an illegal hit based on the position of two wheelchairs (drawing not to scale).

Hitting

The effectiveness of a hit is determined by the position to make a legal hit and by the impulse of a hit. The hit in wheelchair rugby can only be considered legal if the difference in position of two wheelchairs is less than half a wheel diameter plus the maximum length of a front of the wheelchair (35 cm + 46 cm = 81 cm) (see Fig. 3). Therefore, we also calculated the moment in time when the difference in displacement of 81 cm was reached between each of the TIC scores to provide a sport-specific measure.

In the current study, no specific test was performed for the impulse of a hit. Instead, the outcome measures of hitting were based on the results of the acceleration test. The impulse with which an athlete can hit an opponent was defined by sprint momentum (mass of the body and the rugby chair × maximum velocity after 2 m), as commonly used in collision-oriented sports for persons who are able bodied (Baker & Newton, 2008). The maximum velocity per athlete was defined as the maximum velocity at 2 m as opposed to the average velocity during 10 m that was used in the study of Baker and Newton in rugby league in non-disabled athletes. This shorter distance was chosen because a wheelchair rugby court is much smaller (approximately 1/4–1/5 of the size of rugby league field in respectively length and width). Accordingly, a hit is most likely made after a short acceleration.

Statistical analysis

All data were checked for normality using the Kolmogorov–Smirnov test. Only when the data were normally distributed, were parametric statistics used. Any differences between the TIC scores in sports participation and arm impairment were assessed using a chi-square test. Differences in age, height, and weight were assessed using the Kruskal–Wallis test. Single intraclass correlation coefficients (ICCs) were calculated for each of the outcome parameters to examine the reproducibility of the data. An ICC ≥0.60 indicating at least substantial agreement (Landis & Koch, 1977) was required to further analyze the differences between the TIC scores. The trial with the best performance was used for further analysis. Any differences in the left and right directions in the turn test and the left and the right tilt tests were assessed with a paired *t*-test. A multiple step forward regression analysis was used to determine the relative impact of trunk impairment and arm impairment (independent variables) on each of the measured activities (dependent variable). An independent variable was only included if it had a significant relationship with the dependent variable. The Kruskal–Wallis test with a significance level of $P < 0.05$ was used to determine the main effect of the TIC score on the outcome measures: time to complete 10-m sprint and 20-m sprint with turn, tilting height, time to reach a distance of 1, 2, 3, and 4 m in the maximum acceleration test, and sprint momentum. For those activities that were significantly affected by arm impairment in the multiple step forward regression analysis, the Kruskal–Wallis test was repeated without athletes with severe arm impairment. Post hoc, the Wilcoxon rank sum test with a Bonferroni correction for multiple comparisons was performed. All statistical analyses were performed using Matlab (version 7.9.0; R2009b; The Mathworks, INC). The significance level was set at $P > 0.05$.

Table 1. Characteristics of athletes per TIC score

TIC score	Arm impairment (severe/minimum to no)	Wheelchair basketball athletes (*n*)	Wheelchair rugby athletes (*n*)	Athletes playing both sports (*n*)	Median age (range) (years)	Median height (range) (m)	Median mass (range) (kg)
0	7/14	5	14	2	36 (18–50)	1.80 (1.55–1.94)	70 (50–88)
0.5	5/8	6	7	0	29 (20–53)	1.76 (1.23–1.96)	65 (45–101)
1.0	2/9	7	3	1	31 (20–44)	1.80 (1.68–1.95)	70 (56–99)
1.5	0/10	8	2	0	32 (19–59)	1.83 (1.64–1.96)	75 (59–93)

Table 2. Sport wheelchair characteristics per TIC score

TIC score	Median wheel size (range) (inch)	Median sitting height rear (range) (cm)	Median seat angle (range) (°)	Median backrest height (range) (cm)	Median camber angle wheels (range) (°)	Belly binder (Y/N/U)	Hip strap (Y/N/U)
0	25 (24–28)	35 (26–46)	20 (11–32)	38 (28–42)	18 (12–20)	20/2/0	21/1/0
0.5	25 (24–26)	39 (29–48)	11 (7–15)	32 (27–38)	18 (15–20)	5/4/4	9/2/2
1.0	25 (24–26)	48 (38–53)	7 (0–15)	28 (21–31)	16 (12–18)	2/9/0	8/3/0
1.5	25 (25–26)	50 (33–53)	5 (−7 to 22)	27 (21–36)	15 (15–18)	0/9/1	7/2/1

Y = Yes; N = No; U = Unknown.

Results

Table 1 shows the characteristics of the athletes and Table 2 shows the characteristics of the wheelchair rugby equipment per TIC score.

There were no difference in arm impairment ($\chi^2(3, N = 55) = 5.06$, $P = 0.168$) and sports participation ($\chi^2(6, N = 55) = 11.02$, $P = 0.87$) between the TIC scores. Also, there were no differences between the TIC scores in age (Kruskal–Wallis $H(3,50) = 6.09$, $P = 0.11$), height (Kruskal–Wallis $H(3,50) = 2.38$, $P = 0.50$), and mass (Kruskal–Wallis $H(3,50) = 1.84$, $P = 0.61$).

There were differences between the TIC scores in wheel size ($H(3,34) = 3.35$, $P = 0.027$), sitting height (Kruskal–Wallis; $H(3,34) = 17.1$, $P < 0.001$), seat angle ($H(3,34) = 21.8$, $P < 0.001$), backrest height ($H(3,34) = 20.0$, $P < 0.001$), and use of a belly binder (χ^2 $(6, N = 34) = 33.6$, $P < 0.001$). Post-hoc analysis showed that athletes in TIC scores 0 were different from TIC scores 1 and 1.5 for the five wheelchair characteristics. They had a larger wheel size, a lower sitting height, a larger seat angle, a higher backrest, and most frequently used a belly binder. There was no difference between the TIC scores in the camber angle of the wheels ($H(3,34) = 5.7$, $P = 0.13$) and the use of a hip strap (χ^2 $(6, N = 34) = 3.03$, $P = 0.804$).

The ICCs for all activity tests were ≥0.60. See Table 3.

Table 3. Intraclass Correlation Coefficients per test

Test	Intraclass Correlation Coefficient (ICC)	95% confidence interval
Sprint test	0.98	0.93–0.99
Turn test left	0.94	0.91–0.96
Turn test right	0.88	0.82–0.93
Tilt test left	0.61	0.45–0.75
Tilt test right	0.78	0.67–0.86

The step forward regression analysis (Table 4) revealed that the explained variance by trunk impairment was larger than that by arm impairment for the time to cover the first 2 m, the tilt test, and in sprint momentum. Arm impairment was not included in the step forward regression model for the tilt test. And the time to cover the first meter was used as a dependent variable. For the time to cover 4 m, the 10-m sprint, and the turn test, the explained variance by arm impairment was larger than the explained variance by trunk impairment. The total explained variance ranged from 23% for the time to cover the first meter to 37% for sprint momentum, the tilt test left, and the time to cover 3 and 4 m.

The performance on the 10-m sprint test per TIC score for all athletes and athletes without severe arm impairment is shown in Fig. 4.

The Kruskal–Wallis test revealed a significant difference in the 10-m sprint test between TIC scores ($H(3,51) = 10.9$, $P = 0.012$). Post-hoc analysis showed a significant difference between TIC scores 0 and 1.5. However, if only athletes without severe arm impairment were taken into account, the Kruskal–Wallis test showed no significant difference between the TIC scores ($H(3,41) = 5.07$, $P = 0.17$).

Figure 5 shows the performance of the turn test to the left and the right for each TIC score. There was no difference between the left and right turn test $t(54) = -0.68$ ($P = 0.50$).

A significant difference in the turn test between the TIC scores was found ($H(3,51) = 3.93$, $P = 0.019$).

Table 4. Step forward regression analysis with trunk and arm impairment as independent variables and activity as dependent variable

Output	Trunk impairment factor a (placed in forward regression) (P)	Arm impairment factor b (placed in forward regression) (P)	Constant factor c	R^2
Sprint test	−0.11 (2) (P = 0.049)	−0.65 (1) (P < 0.0001)	+4.47	0.33
Turn test left	−0.25 (2) (P = 0.039)	−1.31 (1) (P < 0.0001)	+10.1	0.33
Turn test right	−0.26 (2) (P = 0.028)	−1.30 (1) (P < 0.0001)	+10.1	0.35
Tilt test left	5.06 (1) (P < 0.0001)		−0.32	0.37
Tilt test right	5.27 (1) (P < 0.0001)		−0.22	0.32
Acceleration 1 m.	−0.061 (1) (P = 0.0002)		+0.87	0.23
Acceleration 2 m.	−0.074 (1) (P = 0.0001)	−0.18 (2) (P = 0.013)	+1.55	0.33
Acceleration 3 m.	−0.096 (2) (P = 0.004)	−0.29 (1) (P = 0.0001)	+2.10	0.37
Acceleration 4 m.	−0.11 (2) (P = 0.01)	−0.40 (1) (P < 0.0001)	+2.61	0.37
Sprint momentum	10.9 (1) (P < 0.0001)	20.2 (2) (P = 0.022)	+17.3	0.37

Only the significant independent variables are included.

Formula for each of the outcome parameters: Outcome measure = factor a × TIC + factor b (four categories) × arm impairment (two categories) + factor c.

Explained variance = R^2.

Post-hoc analysis showed a significant difference between TIC scores 0 and 1.5. However, for athletes without severe arm impairment, there was no significant difference in time to complete the turn test between the TIC scores (H(3,41) = 5.4, P = 0.14).

For the tilt test, the tilting height for each of the TIC scores is shown in Fig. 6.

There was no difference between left and right (t (53) = −0.70, P = 0.48).

The Kruskal–Wallis test revealed a difference in tilting height, both left and right, between the TIC scores; left (H(3,50) = 40.0, P < 0.001), right H (3,50) = 37.8, P < 0.001). Post-hoc analysis showed a significant difference between TIC score 0 and TIC score 0.5, 1.0, and 1.5. A large range in tilting height was noted for TIC score 1.0 and 1.5. Therefore, additional post-hoc analysis using a Mann–Whitney U test was done. This showed athletes in TIC score 1.0 who played wheelchair rugby and those who played basketball in the least competitive leagues showed significantly lower tilting height (median 2.95 cm; range 0.5–3.0 cm) than athletes who played basketball in the highest competitive national league or on the national team (median 16 cm; range 7–35 cm) (U = 45, P = 0.004). Such a difference was not found in athletes with TIC score 1.5 (U = 25, P = 0.67).

Results for the acceleration test, the time to complete 1 and 2 m for each TIC score, are shown in Fig. 7. There was a significant difference in the time to complete both 1 and 2 m between the TIC scores (H(3,51) = 14.2, P = 0.0026 and H(3,51) = 16,0, P = 0.0012, respectively). Post-hoc testing revealed that athletes in TIC score 1.5 completed the two tests in significantly less time than athletes in TIC score 0.

Table 5 shows the distance needed to reach a difference in position of 81 cm between each of the TIC scores. On average, after pushing over a distance of 3.19 m from standstill, athletes with TIC score 1.5 reached a distance of 81 cm compared to athletes with TIC score 0.

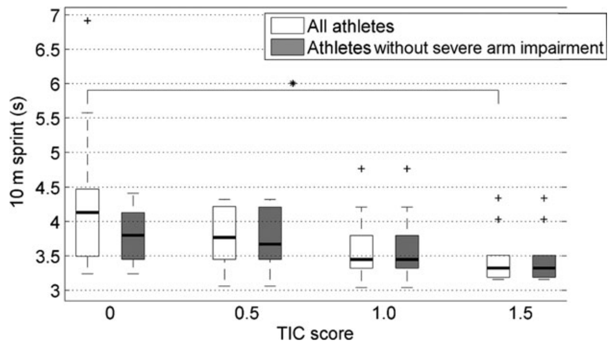

Fig. 4. Boxplot of the time needed for the 10-m sprint per TIC score. Middle line = median, Lower margin = lower quartile, Upper margin = upper quartile, Whiskers = range, + = extreme value, * = significant difference between the TIC scores for all athletes (including athletes with severe arm impairment).

Figure 8 shows the impulse of a hit, calculated by the sprint momentum. There was a significant difference in sprint momentum between the TIC scores according to the Kruskal–Wallis test (H (3,51) = 15.9, P = 0.00012); post-hoc analysis showed differences between TIC score 0 and TIC score 1.0 and 1.5.

Discussion

The aim of this study was to assess the impact of trunk impairment, measured by the TIC, on wheelchair activities that determine performance in wheelchair rugby. Because of the nature of wheelchair rugby as a contact team sport, performance is determined by three tactics: (a) avoiding a hit, in which acceleration and maneuverability play a key role; (b) hitting, in which acceleration, peak speed and impulse of a hit play a key role; and (c) freeing

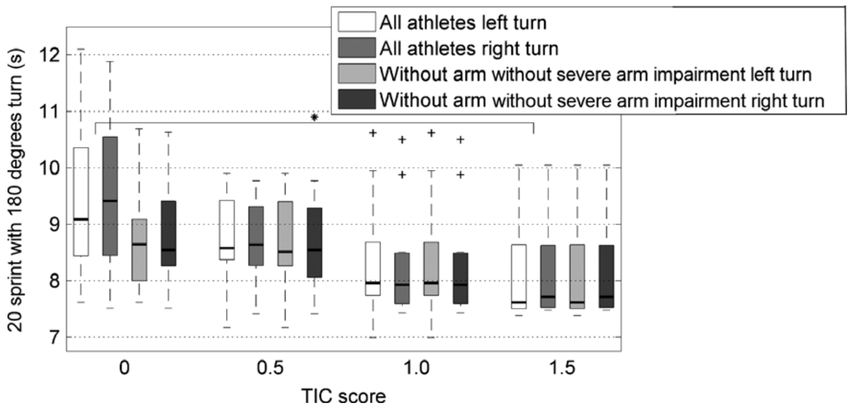

Fig. 5. Boxplot of the time needed for the 20-m sprint with 180° turn per TIC score. Middle line = median, Lower margin = lower quartile, Upper margin = upper quartile, Whiskers = range, + = extreme value, * = significant difference between the TIC scores in both left and right turn for all athletes (including athletes with severe arm impairment).

oneself from being held by the opponent's chair (also called a pick), in which impulse of a hit and tilting the chair play a key role (Orr & Malone, 2010; Malone et al., 2011). Based on a multiple regression analysis for standardized wheelchair activities representing the three tactics that determine sport performance, results showed trunk impairment affected all these activities. The strongest effects were found on acceleration in the first meter, impulse of a hit, and tilting the chair.

Differences in acceleration between athletes determine the distance between the two chairs, and are therefore a key factor in determining if a legal hit is allowed (0.81 m or less, Wheelchair Rugby International Rules, 2015). In examining acceleration, the impact of trunk impairment measured by the TIC was most pronounced in the first meter from standstill. Between 2 and 3 m, the impact of arm impairment became larger than the impact of trunk impairment. These findings are in agreement with a previous study in wheelchair racing, showing that impairment in trunk muscle strength did not affect a 15-m sprint (Vanlandewijck et al., 2011b). In a related study, involving only persons without impairment, Vanlandewijck et al. (2011a) found that active trunk flexion occurred only in the first push and after that the trunk barely moved, thus creating a stable basis for the arms to push. This result indicates that trunk movement contributes to force exerted on the hand rims mainly in the first push from standstill. Within the limits of a wheelchair rugby court (28-m long and 15-m wide), athletes push on average a distance of 9.75 m per bout of activity (Sporner et al., 2009). Therefore, in a game situation, athletes with TIC scores 0.5–1.5 will reach a position on court in which a legal hit by an athlete with TIC score 0 can no longer be made. In addition to that, athletes with TIC score 1.5 will push themselves in a position where a legal hit can be made by athletes with TIC

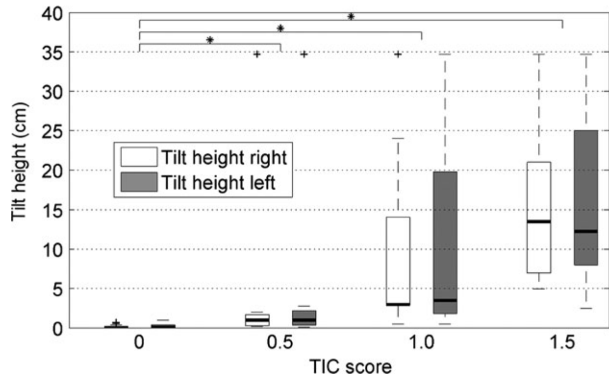

Fig. 6. Boxplot of tilt height per TIC score. Middle line = median, Lower margin = lower quartile, Upper margin = upper quartile, Whiskers = range, + = extreme value, * = significant difference between the TIC scores for both left and right tilt height.

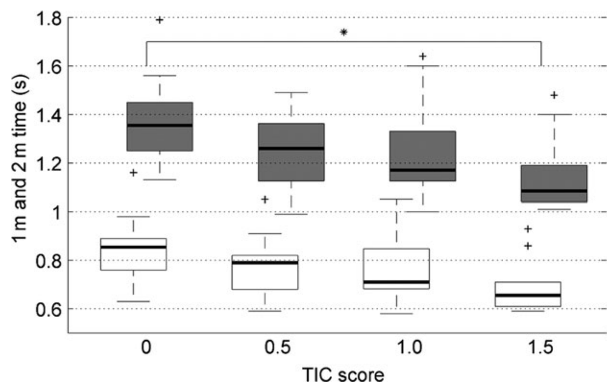

Fig. 7. Boxplot of the time to push 1 m and 2 m in the acceleration test per TIC score. Lower (white) box plots represent the time to push 1 m. Upper (gray) box plots represent the time to push 2 m. Middle line = median, Lower margin = lower quartile, Upper margin = upper quartile, Whiskers = range, + = extreme value, * = significant difference between the TIC scores for both time to push 1 m and 2 m.

Table 5. Distance (m) needed to reach a difference of 81 cm between athletes per TIC score

TIC score	0	0.5	1.0	1.5
0	x			
0.5	6.74	X		
1.0	4.50	10.60	x	
1.5	3.19	6.57	18.60	X

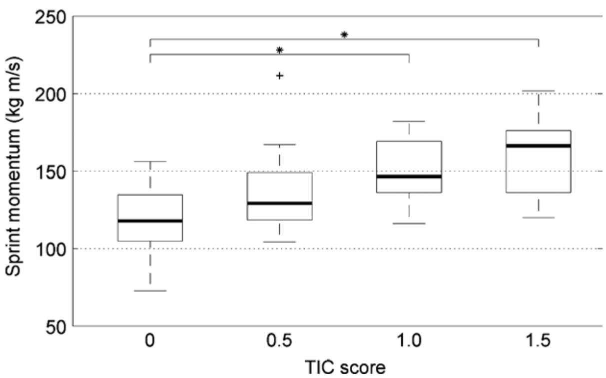

Fig. 8. Boxplot of the sprint momentum per TIC score. Middle line = median, Lower margin = lower quartile, Upper margin = upper quartile, Whiskers = range, * = significant difference between TIC scores.

score 1.5 or 1.0 and cannot be made by athletes with TIC score 0.5 (see Table 5).

The second factor in effectiveness of a hit is measured by sprint momentum. Athletes with TIC score 1.0 and 1.5 had a higher sprint momentum than athletes with TIC score 0. The higher sprint momentum was mainly due to a higher maximum velocity. Body mass was not significantly different between the TIC scores. Hence, the ability to push their chair into a position relative to the chair of the opponent in which a legal hit can be made in combination with the larger impulse of a hit, make the athletes with TIC score 1.0 or 1.5 much more proficient in both avoiding and making a hit than athletes with TIC score 0.5 or 0.

The third tactic that determines performance in wheelchair rugby is the ability of the athlete to get out of a pick in which impulse of a hit and tilting the chair play a key role. The height needed to tilt the wheelchair out of a pick depends on the position of the wheelchair in relation to the wheelchair of the defensive athlete, the height of the bumpers, and the camber axis of the wheels (Orr & Malone, 2010; Wheelchair Rugby International Rules, 2015). A tilting height of at least 5 cm can be seen as an effective tilt. Almost all athletes who could reach sufficient height in the tilt test had TIC scores of 1.0 and 1.5. Hence, athletes with TIC scores 1.0–1.5 are more proficient in getting out of a pick because they can tilt their chair with sufficient height in addition to a higher sprint momentum.

Contrary to that hypothesized based on expert opinion, in the present study, trunk impairment did not have a major impact on maneuverability, which is important to avoid a hit. According to classical biomechanics, angular velocity is determined by linear velocity divided by the distance of the center of mass to the vertical axis of rotation and angular velocity is increased by decreasing the distance of the body mass to the vertical axis of rotation (Podolsky et al., 1990). The position of the center of mass (of the athlete and the wheelchair) in relation to the vertical axis of rotation in the turn test (center of the semi-circle) was determined by the position of the athlete seated in the wheelchair. There was hardly any option for variation of the position of the center of mass due to the enforced narrow curve and the equipment (wheelchair and strapping) that was used (Orr & Malone, 2010). Therefore, with the current rules on equipment in wheelchair rugby, velocity of the turn only depends on the linear velocity.

It must be noted that the athletes in this study were allowed to use their own equipment during all tests to reflect sport-specific performance, with the exception of the tilt test. The athletes in TIC score 0 used a wheelchair with a lower sitting height, a larger wheel size, a larger seat angle, and a higher backrest height, and they strapped themselves to their backrest with a belly binder, most likely to compensate for severe instability of the trunk during wheelchair activities. The larger wheel is often used to compensate for severe arm impairment that was more prevalent in TIC score 0 than in the other TIC scores (Mason et al., 2013). The use of personalized equipment may have resulted in an underestimation of the impact of trunk impairment on all tested activities. Moreover, the use of personalized equipment means that the findings are limited to the current game rules. Generalization of the findings to other wheelchair sports depends on the equipment permitted per sport. Generalization is possible to sports with common characteristics in the allowed equipment, such as basketball (Mason et al., 2013). However, generalization to sports with rules on equipment that are significantly different, such as wheelchair racing, may be limited (Vanlandewijck et al., 2011b). Furthermore, it is important to emphasize changes in sport rules and equipment cannot be made without considering the related effects on classification systems.

A limitation of the present study was the use of two categories for arm impairment, a simplification of the seven categories of sport classes for arm impairment in wheelchair rugby. (Orr & Malone, 2010; Morgulec-Adamowicz et al., 2011). Athletes with manual muscle test grade 3 or less in any of the muscles around the shoulder, elbow, and wrist were all in the class “severe arm impairment”, whereas athletes with manual muscle testing grades 4–5 for all muscles around the shoulder, elbow, and wrist were in the class “minimum to no arm impairment”(Hislop & Montgomery, 2007). This grouping, that was chosen because of the limited number of participants in each of the seven categories for arm impairment used wheelchair rugby classification, may have caused an underestimation of the impact of the most severe arm impairment and an overestimation of the impact of the least severe arm impairment.

A second limitation is the low number of athletes with TIC scores 0.5–1.5 in wheelchair rugby (Altmann et al., 2013). To increase the numbers in TIC scores 0.5–1.5, wheelchair basketball athletes were recruited. Because there is large overlap in activities that determine performance between the two sports, the impact of differences in training and skill development was expected to be limited (Frogley, 2010). However, this assumption did not appear to be correct for tilting the chair. Interestingly, those athletes in TIC score 1.0 who played wheelchair basketball could tilt much higher than those who played wheelchair rugby. An explanation may be that tilting is a frequently used skill in wheelchair basketball to enhance overhead reach and thus is a well-trained activity (Frogley, 2010; Orr & Malone, 2010). Nevertheless, allowing wheelchair basketball athletes to participate was a good choice for this activity. The results suggest that after specific training for tilting, wheelchair rugby athletes with TIC score 1.0 might also be able to tilt their chair.

Perspectives

In summary, the assessment of the impact of impairment on activities that determine performance in Paralympic sports is a challenge, but essential to achieve evidence-based classification systems (Tweedy & Vanlandewijck, 2009). This is even more complex in team sports because multiple activities determine performance and these activities depend on the athlete’s role in the team. This study shows that athletes with higher TIC scores are more proficient in wheelchair rugby than athletes with lower TIC scores, because of the impact of trunk impairment on avoiding a hit, effectiveness of a hit, and the ability to free oneself out of a pick. Generalization of these findings to other sports depends on the activities that determine performance and the rules on equipment in the specific sport. Future assessment of the impact of impairment on performance in wheelchair rugby should address arm impairment in more detail.

Key words: Paralympic sport, wheelchair court sport, wheelchair basketball, activity limitation, classification.

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