Cluster analysis of impairment measures to inform an evidence-based classification structure in RaceRunning, a new World Para Athletic event for athletes with hypertonia, ataxia or athetosis.

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Abstract

RaceRunning enables athletes with limited or no walking ability to propel themselves independently using a three-wheeled frame that has a saddle, handle bars and a chest plate. For RaceRunning to be included as a para athletics event, an evidence-based classification system is required. This study assessed the impact of trunk control and lower limb impairment measures on RaceRunning performance and evaluated whether clusters analysis of these impairment measures produce a valid classification structure for RaceRunning.

The Trunk Control Measurement Scale (TCMS), Selective Control Assessment of the Lower Extremity (SCALE), the Australian Spasticity Assessment Scale (ASAS), and knee extension were recorded for 26 RaceRunning athletes. Thirteen male and 13 female athletes aged 24 (SD=7) years participated. All impairment measures were significantly correlated with performance (rho=0.55-0.74). Using ASAS, SCALE, TCMS and knee extension as cluster variables in a two-step cluster analysis resulted in two clusters of athlete. Race speed and the impairment measures were significantly different between the clusters ($p<0.001$). The findings of this study provide evidence for the utility of the selected impairment measures in an evidence-based classification system for RaceRunning athletes.

Key words: Disability sport, RaceRunning, classification, Cerebral Palsy, Para Athletics, coordination,

Funding: This work was supported by funding from Cerebral Palsy International Sport and Recreation Association (CPISRA) for travel and accommodation costs associated with the data collection.

Disclosure statement: The authors report no conflict of interest.

Introduction

RaceRunning allows people who are not able to functionally run and may have limited or no ability to walk or propel a wheelchair, to propel themselves using a three-wheeled running frame. The RaceRunning frame supports the athlete by way of a saddle and anterior trunk support plate [1,2]. The athletes propel themselves using their legs and can steer with their arms.

In October 2017 RaceRunning was accepted as a World Para Athletics (WPA) event for athletes with a brain injury leading to three distinct types of coordination impairment namely hypertonia, ataxia and/or athetosis (HAA) or a mixture of these. RaceRunning provides a competitive track event for those with more severe coordination impairments [3]. The original classification for RaceRunning was developed by Cerebral Palsy International Sport and Recreation Association (CPISRA) and consists of three classes; RR1, RR2 and RR3 with athletes in RR1 being those with the highest and those in RR3 with the lowest activity limitation [4]. The physical assessment in this classification includes assessments of spasticity selective motor control, ataxia and trunk control. However, this classification is based on expert opinion and not on scientific evidence.

As specified in the IPC Classification code [5], all para sports are required to have a classification system which is based on evidence derived from rigorous descriptive science [6,7]. The purpose of an evidence-based system for classification is to promote participation by minimising the impact of eligible types of impairment on the outcome of the competition. This means that athletes with a similar level of activity limitation due to their impairment should be in the same class and competing against each other. Two key components in classification research are the selection of impairment measures and the determination of the strength of association of these measures with performance or performance indicators [6]. As a result of the call for classification research based on sound taxonomy and scientific principles, research has addressed the association between impairment, activity limitation tests and sports performance or indicators of sports performance in athletes with an impairment of muscle strength or limb deficiency e.g. [8-11], those with HAA [2,12-16] or a mixture of eligible impairments as in para swimming [17].

In a previous study, our research group investigated the association between the severity of a range of impairment measures and 100m speed in 31 RaceRunning athletes [2]. Moderate to strong correlations were found between measures of impairment (lower limb selective voluntary motor control, spasticity, manual muscle strength and range of motion) and 100 m RaceRunning performance.

However, there is evidence from several clinical studies that muscle strength, one of the impairment measures in this study, can be improved in young people with cerebral palsy [18,19] and hence further research is needed to explore the resistance to training of isometric strength measures used for classification [20]. Another limitation of our study was the lack of inclusion of a measure of trunk function. The importance of trunk function for both gait and sports performance has been recognised and supported by findings in studies both with para-athletes [9] and children with CP [21]. Finally, our previous study [2] only demonstrated the association between impairment measures and sport performance and did not explore the existence of natural clusters that could inform the development of sport class profiles [7].

The first aim of this study was therefore to assess the association between measures of trunk control in addition to lower limb selective voluntary motor control, spasticity and knee range of motion (but not strength) and RaceRunning performance over both 100m and 200m. Unlike the 100m, the 200m involves a bend and thus may place higher demands on upper limb and trunk control. These two events were selected because these are the two most popular events, thus allowing more athletes to be included in the analysis. Furthermore, the 100m is the only RaceRunning event currently on the program at international WPA competitions.

The second aim was to investigate the existence of natural clusters in order to inform sport class profiles and allocation in an evidence-based RaceRunning classification system.

Methods

Participants

Female and male athletes with hypertonia, ataxia, athetosis or a combination of these, competing in the CPISRA RaceRunning classes RR1, RR2 or RR3, aged between 14 and 45 and with at least one year of RaceRunning experience were eligible for inclusion. The majority of the athletes were recruited at the international RaceRunning Camp & Cup in 2017. The study protocol was approved by the Queen Margaret University Research Ethics Committee. All participants gave informed consent or where appropriate, assent prior to taking part. For those under 16 years of age parental consent was also obtained. Gender, age, Gross Motor Function Classification System (GMFCS) level [22], number of years of RaceRunning experience and CPISRA RaceRunning classification were collected as descriptive measures. Participants' official season's best race times (i.e. not those wind assisted) for 100m and

200m were used to derive the average running speeds that were then used as measure of sport performance in the analysis. The average running speed over 100m was also corrected for leg length using the equation proposed by Hof [23] resulting in a dimensionless measure of running speed.

Potential classification measures

Hypertonia, selective voluntary motor control (SVMC), passive range motion and trunk control were assessed in all athletes by an experienced specialist neuro-paediatric physiotherapist who is also a national IPC and CPISRA classifier for athletics (NT) with the assistance of a final year physiotherapy student (OC). The student was familiar with performing this type of clinical assessment through her training as a physiotherapist and was trained by the specialist physiotherapist to assist with the measures.

Sanger et al. [24] describe hypertonia can present as spasticity, which is defined as a velocity-dependent resistance of a muscle to stretch, and dystonia which involves involuntary sustained or intermittent muscle contractions. Spasticity of the hip adductors, knee flexors (i.e. hamstrings), knee extensors (i.e. quadriceps) and plantar flexors (i.e. gastrocnemius) was measured in both legs using two different scales: the Ashworth Scale (AS) [25,26] for which the speed of the muscle stretch is not prescribed, and the Australian Spasticity Assessment Scale (ASAS). The ASAS [27] was used to assess the velocity dependent component of the resistance against stretching in the same muscles groups as the AS. The ASAS is the spasticity scale used in the current CPISRA RaceRunning classification system while the IPC classification systems use the AS. The inter-rater reliability of the ASAS in children with CP has been reported as good (kappa: 0.87) [27].

The Selective Control Assessment of the Lower Extremity (SCALE) assesses Selective Voluntary Motor Control (SVMC), i.e. the ability to perform isolated joint movements at the hip, knee, ankle, subtalar and toe joints [28]. SVMC was scored as “normal” (2 points) if the athlete could move the tested joint selectively (e.g. without moving other joints), within at least 50% of the possible range of motion and at a physiological cadence cued verbally by the examiner (e.g. “flex, extend, flex”). If any deviation in performance occurred (movement performed slower, below 50% of range of movement, with movement in one other joint), selectivity was regarded as “impaired” (1 point). The score “unable” (0 points) was given if no joint movement could be made or if the movement could only be performed while simultaneously moving two or more other joints. The validity of the SCALE has been established by strong correlations (rho> 0.8) with the Gross Motor Functioning Classification System (GMFCS) [28,29] and the Fugl-Meyer Test (items III-IV) [29] in children with spastic CP. The same studies also demonstrated a high level of inter-rater reliability (ICC > 0.8).

Our previous research showed that out of the 10 measures of lower limb range of movement, only knee extension was significantly associated with RaceRunning performance [2]. For this reason, only knee extension was measured to the nearest degree using a clear plastic rigid goniometer. A lack of knee extension (knee flexion contracture) was recorded as a negative number. Kilgour et al. [30] reported high Intra-session reliability (ICC > 0.9) for passive range of motion measures in children with CP.

Trunk control was assessed using the Trunk Control Measurement Scale (TCMS). The TCMS is a 15-item assessment that examines sitting balance [31]. The first five items assess static sitting balance followed by ten items assessing dynamic sitting balance. Dynamic sitting balance is further divided into two subscales, seven items assessing selective movement control and three items assessing dynamic reaching. If an athlete could not sit unsupported or with single hand support for 10 seconds, the remainder of the items were scored as zero, hence leading to a total score of zero.

The validity of the TCMS was confirmed in a study with children with cerebral palsy by moderate to strong correlations with the Gross Motor Function Measure (GMFM) [31] and with centre of pressure measures in sitting [32]. Its inter-rater reliability has been reported to be good (ICC was 0.91) [31].

All tests described above are validated clinical “bench” tests that are designed for use across the spectrum of impairment, from very mild to severely impaired. The original papers describing these tests include detailed descriptions of the assessment items, e.g. starting position of the individual and adaptations allowed for the more impaired.

Data analysis

The TCMS and the SCALE are validated measures in which the scores on individual items are summed to derive a total score. Similarly, the individual ordinal scores for the ASAS and the AS for the four muscle groups and for both legs were also summed to calculate a total score. The support of the RaceRunning frame permits athletes to select a propulsion style in which the less impaired limb or joint can compensate the more severely impaired limb or joint. We believe that the association between summed clinical scales and performance reported both in our previous study [2] and others [21,33] supports the use of these summed ordinal measures until reliable and clinically valid ratio scaled measures become available. Knee extension values (positive indicating hyperextension, negative a knee flexion contracture) of the left and right leg were averaged over both legs.

Because all measures except knee range of motion are based on ordinal data, a non-parametric Spearman correlation coefficient was used to derive the strength of the association between the impairment measures and RaceRunning performance over 100m and 200m.

Impairment measures that were significantly ($p<0.01$) associated with 100 meter time were included as variables in a two-step cluster analysis. A mean silhouette coefficient was calculated to evaluate overall goodness of fit as it is a measure of cohesion and separation. A silhouette measure of less than 0.20 indicates a poor solution quality, a measure between 0.20 and 0.50 a fair solution, whereas values of more than 0.50 indicate a good solution. A k-means cluster analysis both with k=2 and k=3, as the existing classification has three classes, was also performed. We also conducted a linear regression analysis with the same impairment measures to identify the portion of the variance in RaceRunning performance over 100m and 200m explained by these measures [7].

An independent t-test and one way analysis of variance (ANOVA) with post-hoc Tukey tests for pairwise comparisons were used to evaluate whether RaceRunning performance (race speed) was different between the clusters identified and between the current three RaceRunning classes respectively. For the impairment measures, a non-parametric Mann-Witney U test was used to compare the two clusters while the Kruskal-Wallis tests was used to compare the three classes. Statistical significance was accepted for $p<0.05$. For the post-hoc tests a Bonferroni correction for multiple comparisons was applied ($p<0.017$). Statistical analysis was performed using IBM SPSS Statistics v23.

Results

Thirteen male and 13 female athletes of which 24 with cerebral palsy, participated in this study (Table 1). There were no athletes with only athetosis in this sample. Ten athletes were diagnosed as having a mixture of coordination impairments (i.e. no dominant type), namely spasticity and either athetosis (n=9) or ataxia (n=1). The two athletes whose most dominant impairment type was categorised as ataxia also had a low level of spasticity. Eighteen of these 26 participants were in the top seven of their current class for at least one RaceRunning event. Fifteen of the 26 participants also took part in our previous study [2]. Impairment measures are shown in Table 2. Two participants in the RR1 class had severe dystonia, preventing both the AS and ASAS from being recorded. One participant was not able to sit independently, hence the TCMS for this athlete was scored as zero.

Spearman correlations between all four impairment measures and RaceRunning speed over both 100m and 200m were statistically significant ($p<0.01$) (Table 3). The association between the impairment measures and dimensionless 100m speed is also shown in Figure 1.

Because all impairment measures were significantly associated with RaceRunning performance all could potentially be included in the cluster analysis. However, as the AS and ASAS are measures for similar constructs, only the ASAS (with slightly stronger associations with performance than the AS) and not the AS was included in the cluster analysis.

The two-step cluster analysis identified two clusters for which the average silhouette measure was 0.6, indicating that the overall structure was a solution with good cohesion and separation. A k-means cluster analysis with k=2 resulted in exactly the same two clusters as the two-step cluster analysis, suggesting that the two cluster solution was stable. Linear regression analysis showed that the ASAS, SCALE and TCMS results together explained a significant portion of the variance of the performance both over 100m ($R2=0.537$, $p<0.001$) and 200m ($R2=0.635$, $p<0.001$). The race times as well as the impairment measures were significantly different between the two clusters (Table 4). For comparison, table 5 shows the race times and impairment measures for the participants in this study based on the three CPISRA classes. None of the performance measures were significantly different between classes RR2 and RR3, although some of the impairment measures, trunk control and knee extension, were. Further, the box and whisker plot in Fig 2a shows very little overlap in the 100 meter race times between the athletes in the two clusters, contrary to the k=3 cluster model in which cluster 1 and cluster 2 (the two clusters with the least impaired athletes) attained similar speeds over 100m (Fig 2b).

Comparing class allocation derived from the cluster analysis and the CPISRA classification, cluster 1 consists of all current RR1 athletes that took part in the study and one athlete currently classified as RR2. Cluster 2 consists of all current RR3s athletes and all but one RR2.

Discussion

The current study aimed to (1) analyse the association between a number of impairment measures (selective voluntary motor control, hypertonia, trunk control and passive knee range of motion) and RaceRunning performance in the 100 and 200 m events, and (2) investigate the existence of natural clusters that can form the evidence base for RaceRunning classes. The present study confirmed the results of our previous study, with a slightly different population, that spasticity, selective voluntary motor control and passive range of motion in the knee are associated with RaceRunning over 100m. In addition, the current study showed an association between trunk control and RaceRunning performance, as well as an association between the selected impairment measures and the performance over 200 meters which involves running around a bend. For all impairment measures, a higher impairment was found to be associated with lower RaceRunning performance. Interestingly, initial analysis of the association between lower limb impairments and both 100m and 200m times shows that the correlation coefficients are very similar for the two distances, suggesting that a similar proportion of the variance in performance is explained by lower limb and trunk impairments in both distances. This suggests that upper limb function may not have a very large impact on the 200m time. However, future studies on the impact of upper limb function on RaceRunning performance are needed to confirm this.

Only the total impairment level for both legs (ASAS, SCALE and knee extension) was considered in the analysis of the association with performance and not that of the most affected and least affected leg separately. This decision was based on the fact that all athletes in this study had bilateral lower limb impairments. The RaceRunning frame allows athletes to adapt their propulsion style to the nature and level of their impairment, far more so than in unsupported running, where athletes with severe asymmetry between both legs cannot compensate the limited function of their most affected leg with their least affected leg to the same extent.

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Trunk control

Although the impact of trunk control on walking outcomes has been demonstrated in children with cerebral palsy [21] and adults after a stroke [34], this is the first study which explored whether trunk control is associated with para sport performance.

The impact of the trunk strength, but not trunk control, on sports performance has been investigated for wheelchair track racing [8] and wheelchair rugby [9]. Connick and colleagues [8] measured trunk flexion strength using a specially constructed rig in 32 male wheelchair athletes (T51-T54) and found a strong association between trunk flexion strength and top speed. Also using an instrumented strength test, Altmann et al. [9] showed that lateral trunk force was significantly related to tilting the chair while forward trunk force was associated with acceleration and sprinting momentum. Both studies used specialised equipment to obtain objective measurements of strength that are reliable [35] and ratio scaled. Further, straps stabilising the legs allowed standardisation of the test reducing the possibility of random error. However, these tests of trunk function were regarded as unsuitable for the purposes of RaceRunning classification. Firstly, these tests measured trunk strength rather than trunk control. Trunk strength is probably more directly related to propulsion in sports where the upper body is used for propulsion instead of the lower limbs, including wheelchair racing and wheelchair rugby, and will be a direct measure of impairment particularly in those athletes with impaired muscle power. However, trunk strength may be expected to be a less of a determining factor for sporting success in RaceRunning athletes with HAA. Secondly, standardisation of the testing positions during an instrumented test may be problematic in some RaceRunning athletes with severe flexion contractures, and/or athetosis.

Tests assessing trunk control in this athlete population can be regarded as on a continuum between sport-specific impairment tests and activity limitation tests. The TCMS assesses the execution of multi-joint actions (e.g. reaching forward or to the side) and could thus be regarded an activity limitation test if used in the classification of sporting events where such actions form part of the sport. In RaceRunning however, the frame, saddle, chest support and steering resistance provide stability and take away much of the need to steer in the 100m race and on the straight in the 200m race.
Further, trunk control is potentially less training resistant than the other measures included in this study. Interestingly, systematic reviews have highlighted the lack of evidence for responsiveness of the TCMS and other trunk control measures [36, 37], although more recently a small uncontrolled trial reported an improvement of the TCMS after intensive trunk control focussed training [38]. Further research is needed to verify the extent to which training by RaceRunning athletes can impact the outcomes of tests such as the TCMS used in classification. This could be achieved through monitoring of both elite and more novice RaceRunning athletes at regular intervals [39].

Cluster analysis

This study and our previous study investigated the association between impairment measurements and sports performance, which is the third step in the development of an evidence-based classification system [6]. The next step in this model is the identification of natural clusters in the impairment data which can then inform the formulation of sport classes. So far, such a cluster analysis has been performed in only a few studies that explored the existence of natural clusters in wheelchair rugby [9] ,wheelchair track racing [8] and CP football [15]. Altmann et al. [9] performed a k-cluster analysis with

k=4, one with lateral trunk force and one with forward trunk force as cluster variables. They presented the results against three different activity limitation outcomes: tilting of the chair (lateral trunk force), forward acceleration and propulsion (forward trunk force). Connick et al. [8] used four different measures of strength in their analysis and which yielded four clusters. The current study is the first to investigate the existence of natural clusters in athletes with a brain injury leading to moderate to severe HAA. This study is also the first to use impairment measures for a variety of body function and structure constructs as defined by the International Classification of Functioning, Disability and Health (ICF) framework for CP (codes in brackets) namely spasticity (b735 Muscle tone functions), passive range of motion (b710 Mobility of joint functions) and selective voluntary motor control (b760 Control of voluntary movement functions) [40]. This approach helps to align classification to the ICF framework [41]. A more extensive profiling, i.e. the measurement of a range of impairments may be advantageous in athletes with a brain injury for whom the associations between impairment, activity limitation and sports performance may be more complex than for those with other eligible physical impairments.
Using four different measures of impairment and two different cluster analysis algorithms we demonstrated the existence of two clusters of athletes whose 100m race times and impairment measures were significantly different. Crucial for classification purposes, the clusters showed very little overlap in race times. The data collected in this study would suggest that a three cluster solution is not appropriate as the race times of clusters 2 and 3 (the middle and least impaired class) were not significantly different and showed a high overlap. Interestingly, when comparing the current sport class allocation (i.e. RR1, RR2 and RR3) and the cluster allocation in the two-cluster model of the athletes taking part in the study, nearly all athletes (except one) in the current RR2 and RR3 classes were allocated to cluster 2 (lowest impairment) and all RR1 athletes were allocated to cluster 1 (highest impairment). This demonstrates some degree of similarity between the results of the cluster analysis and the current class structure and thereby strengthens the validity of our results.
It is interesting to speculate about the reasons underlying the finding that athletes in the current RR2 and RR3 classes who have different levels of impairment for some measures (for example spasticity and knee extension) do not show clear differences in their race performance. It is possible that athletes, for example those with relatively high spasticity but a fair to good selective motor control and trunk control have the capacity to compensate for the high spasticity in some of their muscles by adapting their running technique using a fair to good control of their legs and trunk. As a result, those highly trained athletes would be able to achieve similar race times as those athletes in the study who have relatively lower values on the impairment tests. With the inclusion of RaceRunning as a WPA event, it is possible

that more highly trained athletes with a lower impairment, i.e. closer to the Minimal Impairment Criteria, will start to compete in RaceRunning. This may then result in even faster race times for those at the lower end of the impairment spectrum, possibly leading to a stronger association between impairment and sport performance. Future studies should explore whether or not this is the case.

Limitations

This study has several limitations. Although similar to the other two classification research studies in which a cluster analysis was performed, this study has a relatively small sample size with considerable heterogeneity inherent to the population of athletes eligible to participate in RaceRunning. This heterogeneity, for example in GMFCS level and training status could have affected the strength of the correlation between impairment and performance. Also, as discussed above, with RaceRunning now being a WPA event, it is possible that more highly trained athletes will participate in the event, possibly leading to a change in athlete profiles and associations between impairment measures and performance. Further, we did not collect information on therapies such as spasticity management. Since the RaceRunning population presents with moderate-to-severe levels of CP, future studies should consider therapies (e.g. botulinum toxin injections) received by participants.

Recently, studies have reported a distinct impact of each of the three eligible impairment types for athletes with congenital or acquired brain injury or disease (HAA) on performance suggesting that the impact of each of these impairments types should be analysed [16,42]. As all athletes in this study had some level of spasticity, this has likely led to a bias towards the impact of spasticity in our study. Future research should focus on the impact of ataxia and athetosis using outcome measures such as the Scale for the Rating of Ataxia (SARA) [43] and the Dyskinesia Impairment Scale (DIS) [44].

However, as these latter two tests are also not ratio scaled measures, in parallel, the use of instrumented coordination tests such as instrumented lower-limb tapping tests [12,14-16] should be further investigated in the RaceRunning athlete population, who typically have higher levels of impairments than those participating in ambulant para-athletic events and CP football. Instrumented tests such as those described for strength [e.g. 8,9,18] and coordination [12,14,45] in classification research, as well as instrumented tests for spasticity [46] and trunk control [47] used in clinical studies have the advantage that they produce ratio-scaled data and may be more objective compared to ordinal scaled clinical tests used in this study. Ratio-scaled tests may also be more appropriate to detect intentional misrepresentation using Fitts' law [48, 49] than the clinical measures used in this study. On the other hand, classification in athletes with HAA may need to include a range of impairment measures [14] and having a different instrumented test for each impairment may be impractical for routine classification.

Conclusions

This study demonstrated the association between a range of validated clinical outcome measures of trunk and lower limb impairments and RaceRunning performance quantified as race speed both over 100m and 200m. We also showed the existence of two natural clusters using the data of four different impairment measures (range of motion, spasticity selective voluntary motor trunk of the lower limbs and trunk control). Collectively, these results make an important contribution towards an evidence-based classification system for RaceRunning athletes with a brain injury resulting in Hypertonia, Ataxia or Athetosis. Further research will need to confirm these results in a larger sample and focus on athletes with ataxia and athetosis.

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Table 1 Demographic and sports performance characteristics of the participants

	Mean ± SD ; [range]
Age	24(7); [14:43]
Gender (male/female)	13/13
100 meter time (s)	26.31 (6.84); [18.22: 42.02]
200 meter time (s)*	52.11 (11.29); [37.51: 75.48]
Years involved in RaceRunning	4.9 (3.2); [1-12]
Diagnosis (CP /TBI/Tumour)	24/1/1
Hypertonia/ataxia/athetosis/mixed	14/2/0/10
GMFCS (II/III/IV/V)	7/6/10/3
CPISRA RaceRunning Classification (RR1/RR2/RR3)	7/9/10

CP=Cerebral Palsy; TBI= Traumatic Brain Injury; GMFCS=Gross Motor Function Classification Score
*For two athletes a 200m time was not available.

Table 2 Mean and standard deviations of the impairment measure. For the Ashworth Scale and Australian Spasticity Assessment Scale a higher value indicates a higher impairment, for the Selective Control Assessment for the Lower Extremities and Trunk Control Measurement Scale a higher value indicates a lower impairment.

Measure (range of possible values)	**Mean (SD) [range]**
Total Ashworth Scale (0:32)	13.7 (5.3); [5:24]
Total Australian Spasticity Assessment Scale(0:32)	14.5 (5.7); [5:25]
Trunk Control Measurement Scale (0:58)	26(13); [0-48]
Selective Control Assessment for the Lower Extremities (0:20)	10.4 (5.9); [0-20]
Average knee extension (°)*	-3.7(8.9); [-24:10]

*a negative value indicates flexion contracture

Table 3 Spearman correlation coefficients (rho) between the impairment measures and absolute (100m and 200m) and 100m dimensionless speed (100m DL speed).

	100m (n=26)	**200m (n=24)**	**100m DL speed (n=26)**
Total Ashworth Scale	.594*	.733*	-.602*
Total Australian Spasticity Assessment Scale	.647*	.798*	-.619*
Selective Control Assessment for the Lower Extremities	-.654*	-.741*	.619*
Trunk Control Measurement Scale	-.668*	-.737*	.708*
Average knee extension	.572*	.612*	-.603*

*p<0.01

Table 4 Race times and impairment measures for the athletes in the two clusters. P-values were derived from an independent t-test (race times) or Mann-Whitney U test (impairment measures).

	Cluster 1 Mean (SD)	Cluster 2 Mean (SD)	P value	CI of the difference	Cohen's d
100m time (s)	35.72 (5.07)	22.51 (2.69)	0.002	[-16.32: -10.09]	3.4
200m time (s)	65.73(9.76)	46.66(6.07)	<0.001	[-26.38: -11.80]	2.4
Total Ashworth Scale	20.2(2.6)	11.7(4.0)	<0.001	[-12.1:-4.8]	2.6
Total ASAS	21.1(2.3)	12.3(4.7)	<0.001	[-12.9:-4.6]	2.5
SCALE	4.2(3.9)	13.4(4.2)	<0.001	[6.0:13.0]	-2.3
TCMS	10.2(5.4)	33.0(8.2)	<0.001	[16.2:29.3]	-3.4
Average knee extension (°)	13.0(7.0)	-0.4(5.4)	<0.001	[-18.6:-8.3]	2.2

ASAS: Australian Spasticity Assessment Scale; SCALE: Selective Control Assessment of the Lower Extremities, TCMS; Trunk Control Measurement Scale

Table 5 Race times and impairment measures for the participants in the three existing classes. P-values were derived from one way ANOVA (race times) and the Kruskal-Wallis test (impairment measures)

	RR1 Mean (SD)	**RR2 Mean (SD)**	**RR3 Mean (SD)**	**P-value**
100m time (s)	36.69 (4.61)*	24.24 (3.24)	21.60 (2.24)	<0.001
200m time (s)	66.73 (10.56)*	50.68 (6.65)	44.40 (5.79)	<0.001
Total Ashworth Scale	19.5 (1.9)*	14.8 (4.2)	9.41 (4.86)	0.003
Total ASAS	20.4(1.3)*	15.5(4.3)	10.2(6.0)	0.007
SCALE	3.9(3.4)*	10.70(3.9)	14.9(5.2)	0002
TCMS	9.4(5.7)*	26.5(8.6)#	36.9(7.7)	<0.001
Average knee extension (°)	14.5(8.2)*	5.3(5.5)#	-3.8(2.8)	<0.001

*=Post-hoc analysis showing a statistically significant difference between RR1 and the other two classes

#= Post-hoc analysis showing a statistically significant difference between RR2 and RR3

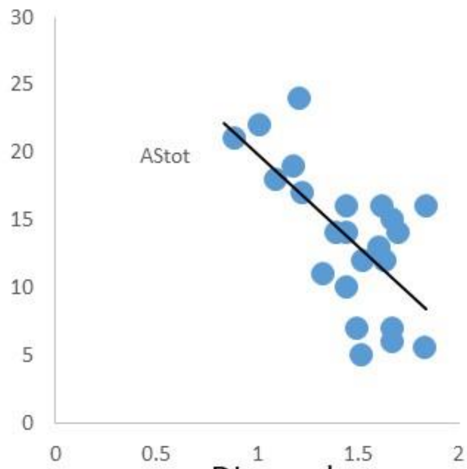


Fig 1a

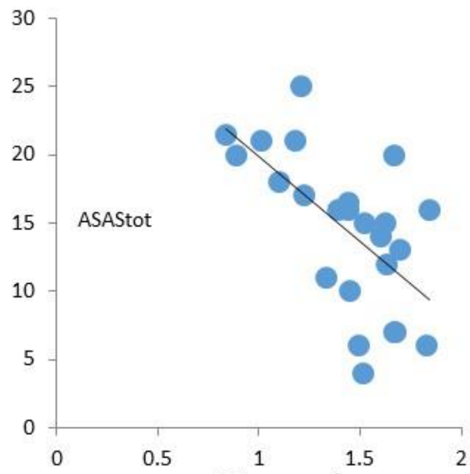
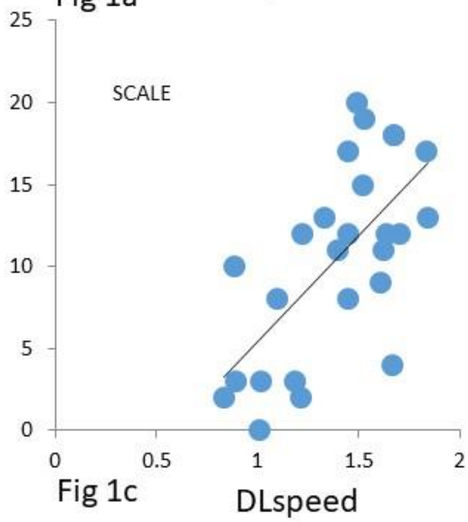


Fig 1b



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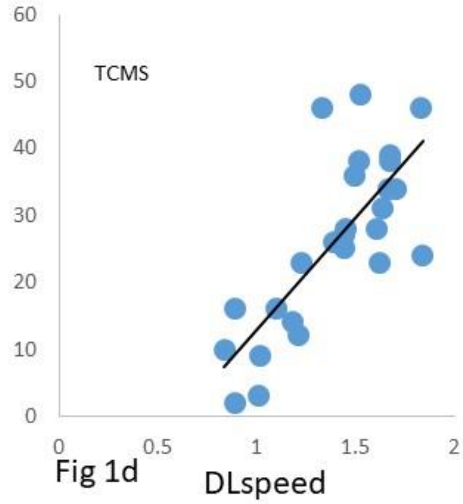

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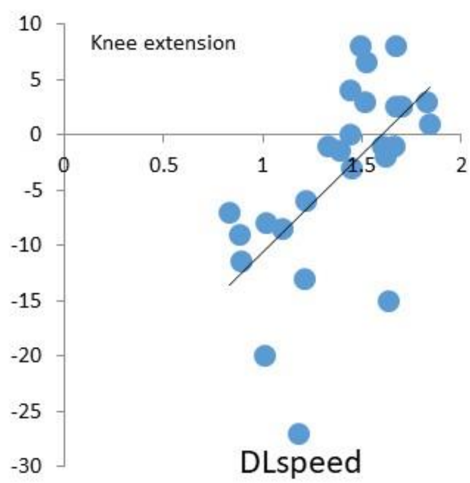

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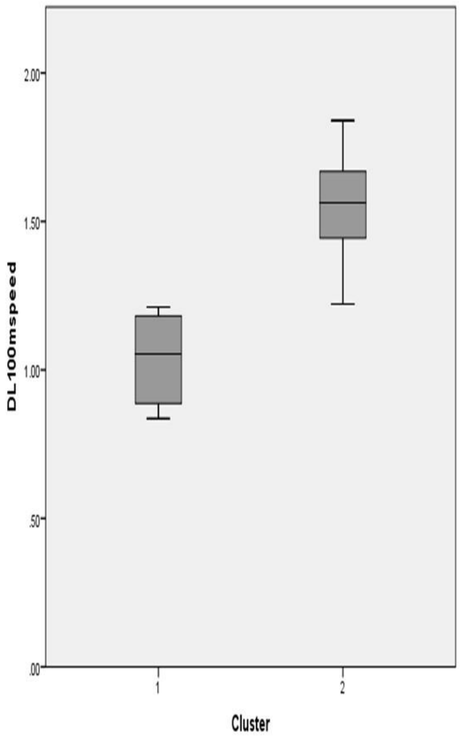
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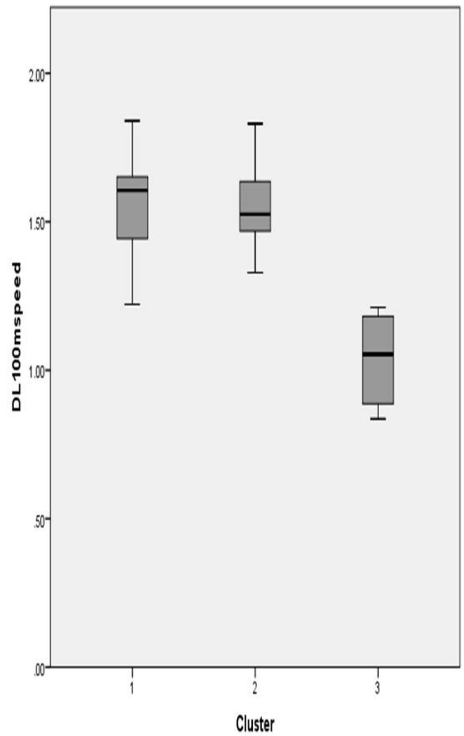
Fig 2a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Cluster
Fig 2b

Figure legends

Fig 1. Association with dimensionless 100m speed with :Total Asworth Scale (Fig 1a), Total Australian Spasticity Assessment Scale (Fig 1b), Selective Control Assessment for the Lower Extremities (Fig 1c), Trunk Control Measurement Scale (Fig 1d) and knee extension averaged over both legs (Fig 1e).

Fig 2. Dimensionless race speed over 100m for the two-cluster solution (Fig 2a) and the three-cluster solution (Fig2b).