Title: London 2012 Paralympic swimming: passive drag and the classification system.

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ABSTRACT

Background The key difference between the Olympic and Paralympic Games is the use of classification systems within Paralympic sports to provide a fair competition for athletes with a range of physical disabilities. In 2009, the International Paralympic Committee mandated the development of new, evidence-based classification systems. This study aims to assess objectively the swimming classification system by determining the relationship between passive drag and level of swimming-specific impairment, as defined by the current swimming class.

Methods Data were collected on participants at the London 2012 Paralympic Games. The passive drag force of 113 swimmers (classes 3–14) was measured using an electro-mechanical towing device and load cell. Swimmers were towed on the surface of a swimming pool at 1.5 m/s while holding their most streamlined position.

Results Passive drag ranged from 24.9 to 82.8 N; the normalised drag (drag/mass) ranged from 0.45 to 1.86 N/kg. Significant negative associations were found between drag and the swimming class ($\tau=-0.41$, $p<0.01$) and normalised drag and the swimming class ($\tau=-0.60$, $p<0.01$). The mean difference in drag between adjacent classes was inconsistent, ranging from 0 N (6 vs 7) to 11.9 N (5 vs 6). Reciprocal Ponderal Index (a measure of slenderness) correlated moderately with normalised drag ($r_P=-0.40$, $p<0.01$).

Conclusions Although swimmers with the lowest swimming class experienced the highest passive drag and vice versa, the inconsistent difference in mean passive drag between adjacent classes indicates that the current classification system does not always differentiate clearly between swimming groups.

INTRODUCTION

The International Paralympic Committee (IPC) is the global governing body of the Paralympic movement and Paralympic Games. One of the biggest challenges facing the IPC is how to provide a fair classification system for each of the Paralympic sports. Classification is essential for the very existence of sports for athletes with a disability.[1] An effective classification system should provide athletes with a disability with an equitable starting point for competition by minimising the impact that their impairment has on the outcome of the event. In 2009, the IPC mandated the development of new, evidence-based classification systems.[2]

Each Paralympic sport's governing body has developed their own classification system. In the current Swimming Functional Classification System, physically impaired swimmers undergo a medical and a technical classification to assess their functional abilities. They are then assigned to a class ranging from 1 (most severely impaired) to 10 (the least impaired). Many different impairment types may compete within a single class (eg, amputee, spinal cord injury, cerebral palsy). Visually impaired swimmers are classed 11–13 and intellectually impaired swimmers are classed 14. The current classification system was developed on expert, but predominantly subjective, opinion, rather than on empirical evidence. There is limited scientific literature available to underpin classification; research has essentially assessed the system but has not led to its modification.

Various research methods have been employed to evaluate the suitability of the Swimming Functional Classification System.[3] Comparisons of the race performances of swimmers in adjacent classes are most often used to judge the system's validity.[1 4] In these studies, the results are dependent on the sample of athletes and the statistical techniques employed. Pelayo et al[5] compared the stroke rate and stroke length among functional classes at the 1995 European Championships. The results supported the logic of the classification system, even though the differences in the stroke index (stroke length × swimming speed) between adjacent classes were not always significant. Wu and Williams[1] examined whether any particular impairment group (eg, Poliomyelitis, Cerebral Palsy, Amputation) had a greater chance of success at the 1996 Atlanta Paralympics. They found that there was equal opportunity for all impairment groups to qualify for a final but that the Poliomyelitis group had relatively less opportunity to win a medal than the other groups.

A swimmer's speed is determined largely by their capacity to produce propulsion effectively while minimising the resistive or drag forces from the water.[6] A fair classification system should, therefore, evaluate objectively an individual's potential to achieve both these important determinants of performance, within the limitations determined by their physical impairment. It could be argued that the current classification system allocates insufficient importance to evaluating a swimmer's drag. The IPC Swimming Classification Manual (2005)[7] considers propulsion in relation to every section of the practical profile used to assign a swimmer to a class. In contrast, a swimmer's drag is assessed in a single, very limited context in the current classification process. Only 'leg drag' (no use of legs or swimmer chooses not to use legs) is addressed in the profile. No consideration is given to how other aspects of a specific impairment may affect the level of drag experienced.

Drag can be measured under two general conditions: passive and active.[8] Passive drag is the resistive force encountered when moving through the water while holding a fixed body position, for example, when gliding; active drag is the resistance experienced when making movements with the arms and legs.

Passive drag can be measured directly by recording the force required to tow the swimmer at a constant speed. It has been suggested that passive drag can contribute significantly to the prediction of swimming performance in able-bodied swimmers.[9] Measurement of active drag still remains a complex and controversial issue, with the most current methods still producing conflicting data.[10] Researchers have found that active drag, in able-bodied swimming, is more dependent on swimming skill and less on an individual's anthropometry.[11] As the fundamental philosophy of the classification system is to evaluate impairment, not skill, passive drag seems the more appropriate measure for classification purposes. Mason et al[12] found that passive drag reflected the amount of propulsion required for a swimmer to swim at maximal speed, and suggested that it may be a good indicator of the future capabilities of a swimmer.

Previous studies have demonstrated that passive drag depends on many factors including body position[13 14] depth and speed of towing15 and body shape and size.[16 17] Until now, only one published study18 has examined passive drag for swimmers with physical impairments. Thirty-four swimmers were divided into three categories (wheelchair user, required walking aid, could walk unaided). Passive drag is related to the severity of the swimmer's impairment. However, this study did not report the participants' level of swimming competence and nor did it attempt to relate the passive drag scores to the current classification system. An unpublished study[19] found that the passive drag of 103 swimmers was more associated with their functional class than with their anthropometry (body mass and height), thus highlighting the importance of passive drag research in evaluating the fairness of the functional classification system.

The aim of this study was to assess objectively the swimming classification system by determining the relationship between passive drag and the level of swimming-specific impairment, as defined by the current Paralympic swimming class. The study will test the hypothesis that those swimmers with the highest level of swimming-specific impairment (low swimming class) will exhibit the highest passive drag and vice versa and that the classification system provides a consistent difference in drag between adjacent classes.

METHODS

Participants

One hundred and thirteen (113) trained competitive swimmers, each with a Paralympic swimming classification, participated in the study (tables 1 and 2). Testing procedures were approved by the lead author's faculty ethics committee and all swimmers provided written informed consent prior to participating. Of the 113 swimmers, 106 competed at the London 2012 Paralympic Games; the remaining seven had competed at national or international level.

Table 1 Characteristics of the participants (mean (SD))

Characteristic	Males (N=69)	Females (N=44)	Combined (N=113)
Age (years)	24.3 (7.1)	21.5 (4.9)	23.2 (6.5)
Height (m)	1.65 (0.26)	1.58 (0.18)	1.62 (0.23)
Mass (kg)	65.3 (12.7)	56.6 (9.0)	61.9 (12.1)

Table 2 Number of participants per swimming class

Class	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11-3**	**14**
Male	3	8	5	10	9	6	13	5	5	5
Female	3	2	0	10	3	4	7	3	8	4
Total	6	10	5	20	12	10	20	8	13	9

Experimental set-up

Passive drag was measured while swimmers were being towed using an electro-mechanical device located at the end of a 50 m indoor swimming pool (figure 1). The device consisted of a drum winch driven by a 0.75 kW electric motor (ABB Ltd, UK) that was controlled by a hand-held unit enabling the towing speed to be set to ±0.01 m/s. Swimmers were attached via an inelastic steel cable. An in-line submersible load cell (DDEN, Applied Measurements Ltd, UK) was attached approximately 5 m in front of the swimmer to measure directly the towing force.

Foam fairings were attached on either side of the load cell to make it neutrally buoyant and to reduce the form drag (figure 2). The load cell was linked to an amplifier (Model ICA, Applied Measurements Ltd, UK) and a 12-bit A-D converter

(PicoLog 1216, Pico Technology, UK) mounted on a pole which was carried by a researcher above the load cell. Force data were sampled at 100 Hz by the A-D converter and captured on a tablet PC (LE1700, Motion Computing, Inc, USA) in real time using custom-built software.

Load cell calibration

A static calibration of the load cell was performed by suspending it vertically and adding 12 known masses incrementally, recording the output for each increment. The linearity of the load cell (figure 3) was less than 1% and its resolution was better than 0.25 N.

Data collection procedure

Swimmers were drag tested in their preferred swimming costume and swim cap. Depending on the nature of their impairment, swimmers were attached to the towing cable using: (1) a small handle, (2) a belt secured under the arms or (3) rubber tubing wrapped around the upper arms. Swimmers were instructed to maintain their most streamlined prone position in the water while holding their breath. All swimmers were towed approximately 35 m at the surface of the water, at a standardised speed of 1.50 m/s. Pilot studies demonstrated that this was a speed that swimmers were comfortable being towed at and at which they were able to maintain a stable, horizontal body position in the water. Each swimmer completed between three and six trials. A time window in which the passive drag force remained reasonably constant for at least 4 s was identified and the mean passive drag force value (D_P) was calculated. The lowest drag value for each participant was used for the subsequent analysis.

Normalisation of passive drag force

To account for the anthropometric profile between swimmers of different size, the passive drag force was divided by body mass (D_P/m) on the assumption that mass was a suitable variable for reflecting a swimmer's size. D_P/m was deemed to be a particularly relevant variable as it provided an approximation of the deceleration (force/mass) which the swimmer would experience if the towing force were suddenly removed. In order to evaluate the effect of swimmer shape on the drag measures, the Reciprocal Ponderal Index (RPI)[20] was calculated using equation (1).

$$\text{Reciprocal Ponderal Index} = \frac{\text{Height}}{\text{Mass}^{1/3}}$$

Statistical analysis

The swimmer's lowest class integer was used in the analysis. The descriptive statistics (mean and 95% CI) were determined for each classification group according to Hopkins.[21] Any significant differences ($p<0.05$) between classifications were identified using a one-way analysis of variance. Scheffe's post hoc analysis was conducted to identify whether there were significant differences between each classification. The strength of the relationship between the passive drag measures and the swimming classification group was determined using Kendall's τ coefficient. The strength of the relationship between the passive drag measures and the RPI was determined using the Pearson Product coefficient (r_P). Correlations were defined as: weak <0.3, moderate 0.3–0.6 or strong >0.6. Note that classes 11–14 were combined into a single, non-physically impaired group for the interclass correlations.

RESULTS

The passive drag force ranged from 24.9 to 82.8 N; the normalised drag force (drag/mass) ranged from 0.45 to 1.86 N/kg. A significant negative association was found between passive drag and swimming class ($\tau=-0.41$, $p<0.01$). The strength of the association was increased when drag was normalised for body mass ($\tau=-0.60$, $p<0.01$; figures 4 and 5).

<< Figures 4 and 5 here >>

Post hoc analysis testing revealed no significant differences ($p>0.05$) in passive drag force, D_P, between the majority of the physical (3–10), visual (11–13) and intellectual (14) impairment classes. The only significant differences ($p<0.05$) in passive drag were between class 3 and classes 9 and 10.

Regarding the normalised drag force, D_P/m, significant differences ($p<0.05$) were found between class 3 and classes 4 and 6–10. There were also significant differences ($p<0.05$) between class 9 and classes 4–6. The class 3 swimmers had a significantly higher normalised drag than all of the visually (11–13) and intellectually impaired (14) swimmers. Conversely, there were no significant differences ($p>0.05$) between the physical impaired swimmers in classes 4–10 when compared with the visually and intellectually impaired swimmers.

There was considerable within-class variability in the passive drag, as evidenced by the SDs and ranges presented in figure 4. When the drag scores were normalised for body mass, the within-class variability reduced substantially in classes 7–14 but remained relatively high in the lower classes. Effect statistics comparing adjacent classes reveal that there was an inconsistent difference between each class (table 3). The interclass difference in passive drag ranged from no difference (between classes 6 and 7) to 11.9 N (between classes 5 and 6).

<< Figure 6 here >>

The swimmers' slenderness measure, RPI, ranged from 0.25 to 0.48 m/kg$^{1/3}$, with a mean of 0.41 m/kg$^{1/3}$. The within-class variability in RPI was considerably greater in classes 3–6 than in classes 7–14. There was a clear trend of an increase in the mean RPI with an increase in swimming class, up to class 6, and then very similar mean RPI scores for the remaining classes. A weak negative relationship was found between passive drag and RPI (r_P=−0.18, p<0.01). The strength of the association increased to moderate when drag was normalised for body mass (r_P=−0.40, p<0.01).

Table 3 Difference in (Δ) passive drag and normalised drag between adjacent swimming classes (mean difference (95% CI)) for physical impairment classes 3–10

	Class 3 & 4	Class 4 & 5	Class 5 & 6	Class 6 & 7	Class 7 & 8	Class 8 & 9	Class 9 & 10
ΔPassive Drag (N)	11.8 (-26.9 – 3.4)	1.4 (-19.1 – 21.9)	11.9 (-23.4 – -0.5)	0.0 (-7.0 – 6.9)	4.7 (-11.8 – 2.4)	0.7 (-9.1 – 7.8)	2.7 (-9.8 – 4.4)
ΔDrag/Mass (N·kg^{-1})	0.44 (-0.66 – -0.22)	0.08 (-0.12 – 0.28)	0.29 (-0.62 – 0.04)	0.23 (-0.42 – -0.05)	0.05 (-0.13 – 0.02)	0.03 (-0.06 – 0.11)	0.06 (-0.19 – 0.07)

DISCUSSION

The Paralympic sport classification systems determine the eligibility of athletes with disabilities to compete in the Paralympic Games and in which categories they can compete. The aim of this study was to assess objectively the swimming classification system by determining the relationship between passive drag and the level of swimming-specific impairment, as defined by the current Paralympic swimming class. It was hypothesised that: (1) swimmers with the highest level of swimming-specific impairment would exhibit the highest passive drag and vice versa and (2) the classification system would differentiate passive drag measures between classes. The study found significant correlations (moderate—strong) between the passive drag measures and the swimmer's current classification. That is, as the severity of swimming-specific impairment decreased, so did the passive drag measures. The first part of the hypothesis was therefore accepted. The second part of the hypothesis was rejected as there were inconsistent differences in the passive drag measures between classes.

The mean passive drag force recorded in this study was 45.9 N. This falls within the range of values reported in previous studies of able-bodied swimmers at the same speed (1.5 m/s), for example, Bixler et al[22] 37.2 N; Mason et al[23] 43.8 N, Takagi et al[24] 59.2 N. However, the range of the drag scores in the current study (24.9–82.8 N) is higher than those typically observed in able-bodied studies.

One of the key findings of this study was the considerable within-class variability in passive drag, as evidenced by the SDs and ranges. When drag was corrected for body mass, this variability decreased substantially in classes 7–14, but remained relatively high in classes 3–6. As the drag measures were made on high-level athletes, these results are unlikely to be due to differences in levels of training within and between the classes. High within-class variability in drag exists mainly because different impairment types compete within a single class (e.g., amputee, spinal cord injury, cerebral palsy). The lower classes may incorporate a greater diversity of impairment types than the higher classes. Hence, they may be more variable in factors that influence drag, such as body shape, strength, coordination and joint range of motion. Within classes 3–6 in particular, some athletes appear to have a substantial advantage over others with regard to passive drag, which in turn may translate to a performance advantage.[9 12] Whether this is an unfair advantage depends critically on whether the swimmer's relatively low drag is a consequence of superior training or whether their impairment type predisposes them to a lower drag than others in their class. If it is the latter, then the current classification system is more advantageous for certain swimmers by placing insufficient weighting on drag assessment. If drag was assigned more importance in the classification process, the within-class variability in drag would be reduced, increasing the likelihood of there being significant differences in drag between adjacent classes.

Despite the athletes in classes 7–10 having very similar normalised drag scores to each other, as well as to elite able-bodied swimmers,[21 22] the swimming speeds of athletes in these classes are not generally comparable.[25] It seems that the capacity to generate propulsion, rather than to reduce drag, is what separates the performances of these groups. Conversely, drag may be more important in discriminating between performances across the lower classes.

Although the visually impaired swimmers in this study could be considered able-bodied athletes physically, their limited vision might have been expected to reduce their spatial awareness and adversely affect their ability to hold a streamline position. This does not appear to have been the case as the passive drag scores for this group were comparable to those found for elite able-bodied swimmers.[21 22] Similarly, there was no evidence to suggest that the intellectually impaired swimmers were less able to streamline their bodies than elite, non-impaired swimmers.

The RPI results indicate that swimmers in classes 7–14 were generally more slender than those in the lower classes. As with the passive drag measures, the RPI presented greater variability in the lower classes, reflecting the greater diversity of impairment types and body shapes in these classes. A previous study[26] reported a very strong correlation (r=0.93) between passive drag and mass:height ratio for swimmers with physical impairments. In contrast, the current study found only a moderate association when passive drag was related to a combination of height and mass (the RPI). The statistical results of the previous study may be explained by the small sample size (N=11), four of whom were of very small stature as they were double-leg amputees.

The purpose of classification should be to minimise the impact of impairment on the outcome of competition. That is, the aim is to ensure that the athletes who win are those with the best combination of anthropometry, physiology and psychology, enhanced to best effect through training and legal technical aids. Therefore, any system must be based on a method of classification that correctly measures and classifies impairments according to the degree to which they limit the relevant activity (in this case, swimming).

A swimmer's body shape and body position in the water will have a significant influence on the amount of drag they experience. This study measured objectively how much drag each swimmer produced when holding their most streamlined position and thus contributed to the body of existing knowledge on how people with disabilities move through the water. Furthermore, the results presented provide a database of passive drag relationships that researchers can compare their Paralympic swimming group with and help guide any intervention on changing the swimmers' body position, where possible.

This study's limitations must be acknowledged. First, the small sample size in some classes limits the scope to generalise the results to a wider population. A larger scale confirmatory study would be the logical next step. Second, the authors were unable to collect impairment-specific data such as strength, range of motion and coordination. These data would have helped explain the observed within and between class variability in the drag measures. Finally, it was not possible to obtain anthropometric measurements on all of the athletes, due to the testing environment. Height and mass data allowed a slenderness index to be calculated, but further measurements would have allowed a more detailed assessment of body shape and size.

CONCLUSION

This study has reported passive drag measures for a range of Paralympic swimmers. There exists a strong relationship between a swimmer's normalised passive drag and their current swimming class. However, there is an inconsistent and often an almost negligible difference in normalised passive drag measures between adjacent classes, indicating that the current classification system does not differentiate clearly between classes. High within-class variability in passive drag, in the lower classes, indicates that some athletes in these classes may have a substantial advantage over others with regard to this performance-related parameter.

What this study adds

- This is the first research to relate the measurement of drag forces (a performance-related measure, relatively independent of skill level) to the current Paralympic classification grouping. A moderate-to-strong correlation was found between passive drag measures and the current swimming class.
- An inconsistent difference in the passive drag measures between adjacent classes and high within-class variability confirms that the current classification system does not give much attention to evaluating drag. This research can help identify where the current classification system may be disadvantaging certain swimmers.

Acknowledgements

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Competing interests

None.

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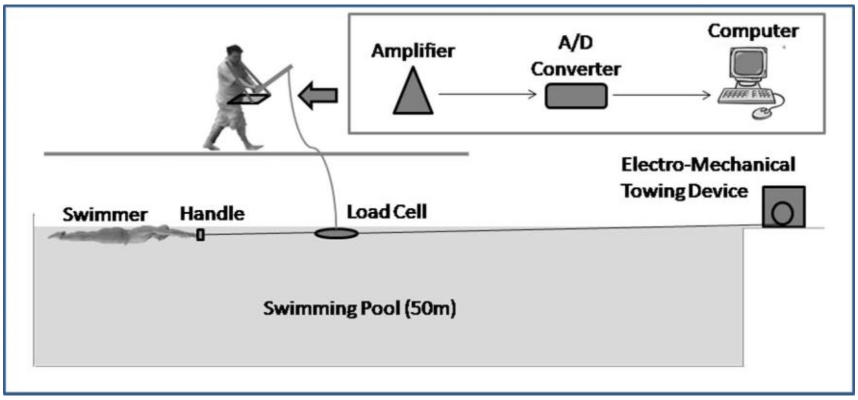
FIGURES



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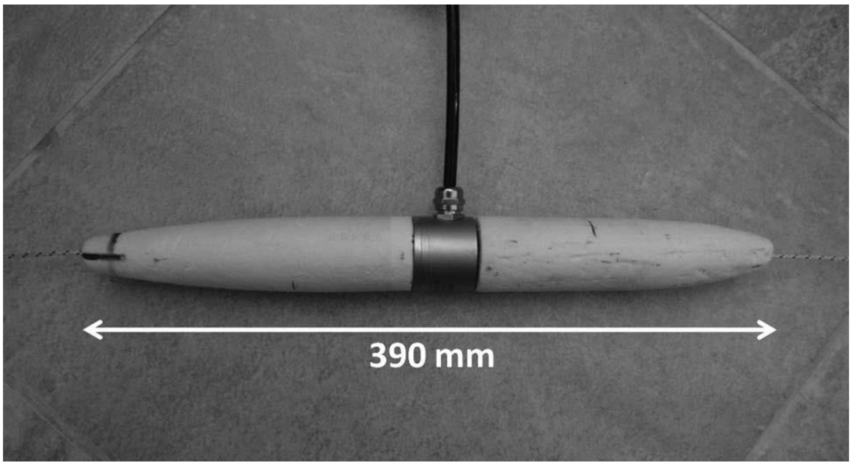
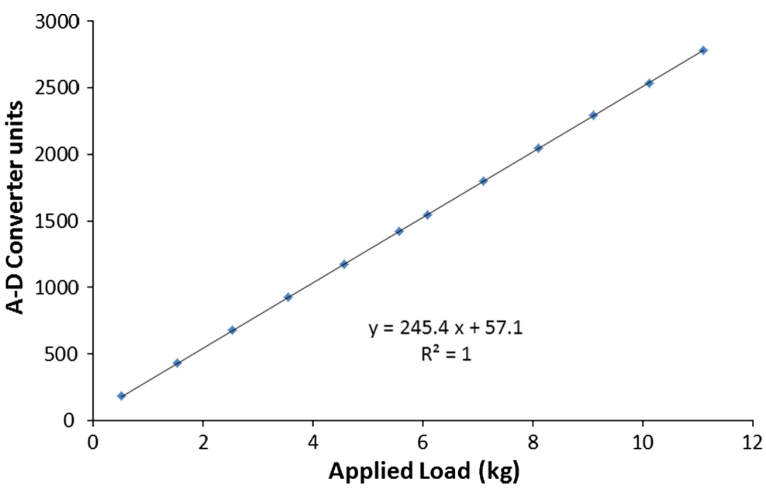


Figure 2



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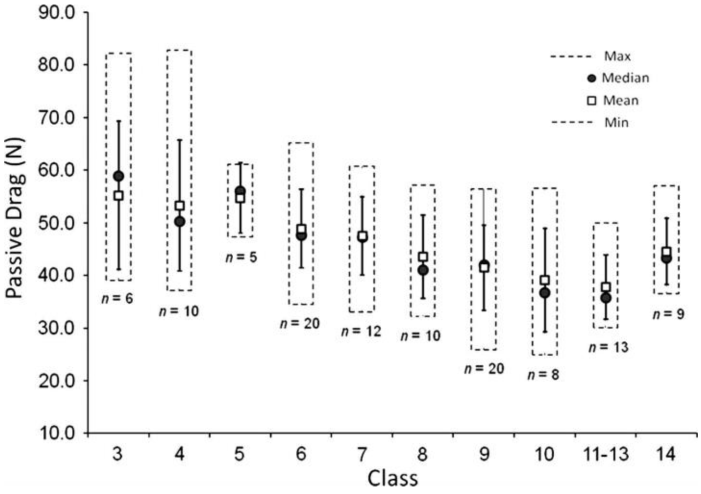

Figure 4

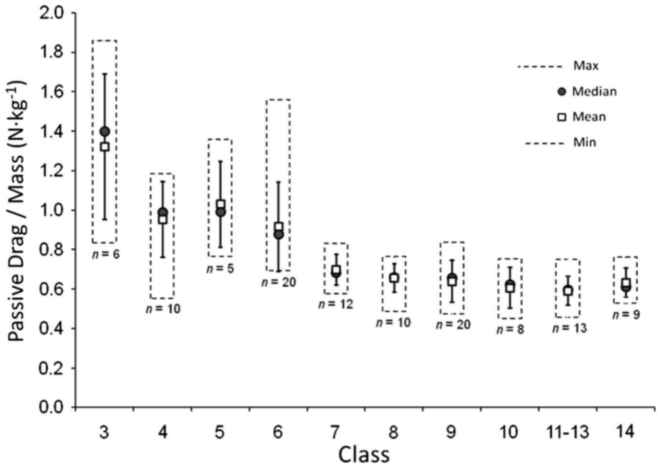

Figure 5

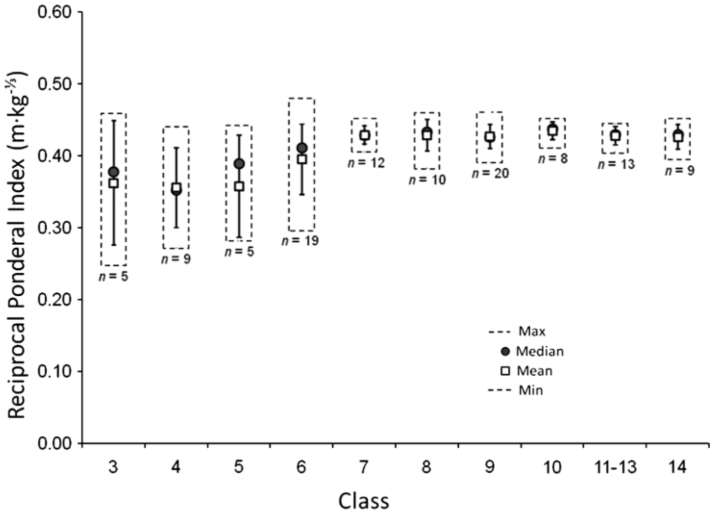

Figure 6