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## Is the visual impairment origin a performance factor? Analysis of international-level para swimmers and para athletes

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1 **Is the visual impairment origin a performance factor?**  
2 **Analysis of international level Para swimmers and Para athletes**

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20 **Abstract**

21 The aim of this study was to investigate the effect of congenital and acquired visual impairments on the  
22 international performance of Para swimmers and Para track and field athletes. We collected results from  
23 visually impaired Para athletes competing in Para swimming or Para athletic events at all IPC-labelled  
24 competitions between 2009 and 2019. The dataset contained 20689 events results. Impairment origin was  
25 collected from the International Paralympic Committee (IPC) website. We separated impairment origin into  
26 two groups to distinguish those with a congenital impairment from those with an acquired impairment. In  
27 visual impairment sport classes (11-12-13), the performance level and the age performance relationship were  
28 investigated according to the impairment origin. In classes 11 and 12, peak performance was achieved earlier  
29 by male and female swimmers with a congenital impairment compared with those who had an acquired  
30 impairment ( $p < 0.05$ ). No differences were present in class 13 or in any class in Para athletics ( $p > 0.05$ ). A  
31 similar performance level was observed among the two sport disciplines for each class ( $p > 0.05$ ). This study  
32 demonstrated that impairment origin can influence the performance pathway among visually impaired  
33 swimmers.

34 **Key Words: swimming; athletics; Paralympic; impairment origin; talent identification; para sport**

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35 **Introduction**

36 One of the challenges that Para sport faces today is the achievement of fair competition. This can be done by  
37 minimizing the impact of an individual's impairment on the outcome so that sporting ability, skill level and  
38 training alone determine success and the final result. Historically, the classification system was based on a  
39 medical diagnosis for all Paralympic disciplines and sport classes. In the 1980s, a sport specific and evidence-  
40 based functional classification system was implemented. However, because of the lack of guidance and  
41 scientific evidence of visual impairment (VI) functional impact, the VI classification system is still based on  
42 a medical diagnosis. It groups athletes with VI into 3 sport classes (Table 1) after an ophthalmological  
43 diagnosis of their impairment based on the World Health Organization (WHO) definition of blindness and  
44 VI(World Health Organization, 2019; World Para Athletics, 2018; World Para Swimming, 2018).

45 The VI classification system is the same for almost all Paralympic disciplines and therefore does not consider  
46 the influence of vision loss on each discipline performances(Ravensbergen et al., 2016). A vision loss seems  
47 to affect cardiovascular and muscular endurance, flexibility, balance, motor learning and motor  
48 performance(Bouchard & Tetreault, 2000; Daly et al., 2009; Skaggs & Hopper, 1996). Few studies investigate  
49 the role of VI on race time in para swimming and para athletics. In both disciplines, 11 classes were found to  
50 be slower than 12 and 13 classes with no significant differences between the latter (Chun et al., 2019; Daly  
51 et al., 2009; Malone et al., 2001). In para swimming, the time to turn was a parameter related to the visual  
52 capacity highlighting the effect of a poorer vision on swimming performance(Daly et al., 2009; Malone et al.,  
53 2001). The development of a sport specific classification system for people with VI is needed but face the  
54 lack of knowledge about the effect of VI on each discipline performances(Tweedy et al., 2016).

55 In order to assess the needs for a sport-specific and evidence-based VI classification system, two studies,  
56 based on a systematic interactive survey method address several key points for Para swimming and Para  
57 athletics classification systems. In both studies, expert panels unanimously agreed that the age at which a VI  
58 is acquired will impact the swimming and running performance and the technical skills acquisitions(Allen et  
59 al., 2020; Ravensbergen et al., 2018). Knowledge and scientific evidence about the difference between  
60 congenital and acquired impairment on sport performance is very limited. It is recognized that observational  
61 learning has an important role in motor and technical skills acquisition(Hodges & Williams, 2007; Weiss et  
62 al., 1998; Wesch et al., 2007). Also, observational learning effect and outcomes is known to be influenced by  
63 age(Ashford et al., 2006). The relationship between the age at which the impairment is acquired and the time  
64 required for skill acquisition will depend on the specific complexity of the sport(Allen et al., 2020;  
65 Ravensbergen et al., 2018).The difficulty to use observational learning in training for athlete with VI could  
66 induce a longer time to acquire motor learning and specific skills (Mann & Ravensbergen, 2018;  
67 Ravensbergen et al., 2016). These observations highlight the need to investigate the age of the acquired VI  
68 and how it could influence performance. To our knowledge, no studies have been conducted comparing  
69 quantitatively the performance level between Paralympic athletes with a congenital impairment (CI) and an  
70 acquired impairment (AI).

71 There is also limited knowledge around career pathways on Paralympic athletes(Patatas et al., 2018).  
72 Identifying key components of developmental pathways can contribute to talent identification and improve  
73 athletes supports(Dehghansai et al., 2021). In this framework, age related performance can add precious  
74 information for athlete development, classification process, and talent identification(Berthelot, Johnson, et  
75 al., 2019; Hogarth et al., 2020; Schipman et al., 2019). Several studies have been conducted on the changes  
76 in performance related to age in Paralympic(Hogarth et al., 2020; Schipman et al., 2019) and  
77 Olympic(Berthelot et al., 2012; Marc et al., 2018) disciplines. Due to physiological and psychological  
78 changes, para swimmers and para athletes showed annual progressions that reach a peak and then decrease  
79 depending on gender, impairment type and event(Hogarth et al., 2020; Schipman et al., 2019). However, at  
80 an individual scale, the age at which the impairment is acquired could also have a major influence on this  
81 pathway. Therefore, it seems necessary to include the impairment origin in the age-related performance  
82 analysis in order to provide information on how it can influence a career pathway.

83 The objective of this study was to investigate the international performances of Para Swimmer (PS) and Para  
84 Athletes (PA) with an AI or a CI. To meet this objective, we first compared the performance level in each  
85 impairment class between the CI and AI groups. Then we investigated the relationship between age and  
86 performance in each impairment class according to the VI origin for the same events. Firstly, it was  
87 hypothesised that PS and PA with acquired VI would perform better than congenital VI. Secondly, it was  
88 hypothesised that performance pathway will be different between CI and AI groups in PS and PA.

89 **Material and methods**

**Data.** Publicly available data was extracted from the IPC website: [www.paralympic.org](http://www.paralympic.org). We extracted each athletes' top annual performance for each event between 2009 and 2019. Before 2009, the data were unavailable on the IPC website. In Para swimming, athletes' times were collected for the following long course events: 50 m freestyle, 100 m freestyle, 400 m freestyle, 100 m butterfly, 100 m backstroke, 100 m breaststroke, 200 m individual medley. For Para Athletics, times were collected for the following events: 100 m, 200 m (only females), 400 m, 1500 m, 5000 m (only males), marathon, and long jump. These events were selected because they were in the Tokyo 2021 Paralympic Games program. In order to have the same number of events for Para swimming and Para athletics, we added the 800 m run for Para athletics, which is not included in the 2021 Paralympic Games program. The following variables were included in the dataset: event type, event time converted to speed ( $m \cdot s^{-1}$ ), year of the event, last and first name, age (in years), sex, and impairment classification. A categorical variable "VI origin" with 3 factors (congenital impairment, acquired impairment, missing information) was added to the dataset. This data was collected from athlete biographies on the IPC website. If the information was missing on the IPC website, the search was extended to a broader internet search to see if the athlete had self-declared his/her VI origin. A congenital impairment (CI) was defined as a VI that presented at birth or in the first 6 months after birth. An acquired impairment (AI) was defined as a PS and PA with previously unaffected vision, but with a visual capacity that is now classified as impaired. For athletes with no recorded VI origin, a third category, missing information (MI) was created.

We defined performance level as the mean performance for the CI group and AI group in each Para swimming and Para athletics event for each class. We defined performance as the best event time converted into speed ( $m \cdot s^{-1}$ ) for each Para swimmer with a congenital impairment (PSCI) and Para swimmer with acquired impairment (PSAI) in each event for each class. Similarly, the best event time for each Para track and field athlete with congenital impairment (PACI) and Para athlete with acquired impairment (PAAI) in each event by classes was defined as the athlete's performance.

**Relative performance.** We analysed the best individual performance of each PS and PA according to VI origin in class 11, 12 and 13 for each event. To do so, we calculated the Relative Performance (RP) for each athlete ( $i$ ) in percentage of the all-time best performance in each event ( $j$ ) and for each class ( $k$ ) (Eqn 1). This method allowed us to compare intra-class performance by grouping all events.

$$\text{Eqn 1 : } RP_i (\%) = \frac{\text{World record}_{jk}}{\text{Best individual performance}_{jk}} * 100$$

**Performance level in each event.** In order to go further in the investigation, we analysed the best individual performance of each PS and PA in each class for the 21 events in each discipline. The performance was calculated in  $m \cdot s^{-1}$  and meters (m) for long jump event.

**Missing data imputation.** In order to minimize missing data (referred as MI group) bias, a missing data imputation method was implemented. We created one thousand datasets for each sport class and each event in which the MI group was distributed in CI and AI groups in a random manner according to a binomial law  $B(n, p)$  with:

$$n : \text{number of missing data in each class and each event}$$

$$p : \text{probability corresponding to the CI/AI groups distribution according to the class and event.}$$

We analysed and compared the performance level between the CI and AI groups on each dataset created. The results are expressed in mean and standard deviation (in percentage) of each dataset that didn't allow us to reject the null hypothesis ( $p > 0.05$ ). Results of the missing data imputation was then compared to our study sample (Performance level analysis result) for each event by class.

**Age related performance according to the VI origin.** In order to investigate the relationship between age and performance, we used the best performance of each PS and PA by age and according to VI origin in each event and for each class.

We modelled the relationship between age and performance according to an Integrative Model of Age-Performance (IMAP1). This model accurately describes the age-related changes of performance in multiple time-series phenotypic traits. IMAP1 (Eqn 2) is based on an enhanced biological foundation (Berthelot, Bar-Hen, et al., 2019). The formula of IMAP1 is:

$$\text{Eqn 2 : } P(t) = a \cdot e^{\frac{b}{c}(1-e^{-ct})} \cdot (1 - e^{d(t-f)})$$

P represents the performance according to t (the time), a and b are two growth parameters, c, d and f are decay parameters. In order to find optimal parameters, we used the method of least squares to employ a method of

141 parameter optimization under constraint. Parameters a, b and c were forced to be higher than 0 and parameter  
142 f was forced to be between 90 and 120. For each event, we calculated the estimated age of peak performance  
143 (EAPP) that corresponds to the maximal estimated performance by age. The quality of each fit was estimated  
144 with the coefficient of determination,  $R^2$ .

145 **Statistical analysis.** We conducted statistical tests to compare the performance indicators within each sample  
146 and therefore, test the effect of the observed factor: the VI origin.

- 147 • To test for performance difference according to each impairment origin group, a Kruskal Wallis test  
148 with a pairwise Wilcoxon test with Bonferroni adjustment was performed in order to control the  
149 multiple tests effects and reduce the probability of type I errors. Data were reported as mean  $\pm$   
150 standard deviation of RP.
- 151 • To test the age performance relationship difference according to impairment origin group we  
152 computed and compared mean EAPP for all events with a Wilcoxon test. Data were reported as  
153 mean  $\pm$  standard deviation of EAPP.
- 154 • For the imputation method, we performed we used a Wilcoxon test to compare the performance level  
155 in the 1000 datasets for each event according to each impairment origin group. Data were reported  
156 as in mean  $\pm$  standard deviation (in percentage) of each dataset that didn't allow us to reject the null  
157 hypothesis.

158 For all statistical analysis, the significance level was set at  $\alpha = 0.05$ . Data processing, graphical visualization  
159 and statistical analyses were conducted in R (version 4.0.3; The R Foundation for Statistical Computing,  
160 Vienna, Austria).

161 **Ethics Statement.** This study was designed and monitored by the IRMES (Institut de Recherche bio-  
162 Médicale et d'Epidémiologie du Sport) scientific committee. It used a research protocol classified as non-  
163 interventional, in which all acts are performed in a normal manner, without any supplemental or unusual  
164 procedure of diagnosis or monitoring. (Article L1121-1 of the French Public Health Code). Due to this non-  
165 interventional protocol and the exclusive use of retrospective data obtained from public sources, this study  
166 did neither require ethics approval nor approval from a Committee for the Protection of Persons. The database  
167 we have built up has been notified to the *Commission Nationale de l'Informatique et des Libertés* (CNIL  
168 statement n° 2216328 v 0), which is supervising data used in France.

## 169 **Results**

170 The Para swimming dataset contained 10619 event times: 6380 events from 408 males; 4239 events from 227  
171 females. The Para athletics dataset contained 10942 event times: 7658 events from 1031 males; 3284 events  
172 from 447 females (**Table 2**).

173 **Relative performance.** The relative performance analysis showed a statistically significant difference  
174 between CI, AI and MI groups ( $p < 0.05$ ) in each sport class in para swimming and para athletics. The RP  
175 were lower in each sport class for the MI group for men and women in Para swimming and Para athletics  
176 (**Figure 1**). Post-hoc tests showed statistically significant differences for MI group with the CI and AI groups  
177 ( $p < 0.05$ ). Between CI and AI groups, the post-hoc tests showed no statistical differences for men and women  
178 in Para swimming and Para athletics ( $p > 0.05$ ).

179 **Missing data imputation.** In each sport class, the missing data imputation method also highlighted a similar  
180 performance level in both disciplines between CI and AI groups with the MI group individuals randomly  
181 distributed (**Table 3**). In Para swimming, for the 400 m freestyle, 76.60 % of the thousand datasets created in  
182 this event didn't allow us to reject the null hypothesis, which is different from our study sample where we  
183 have shown a statistically significant performance level difference. In Para athletics, for the 400 m, in class  
184 13, 77.70 % of the thousand datasets created in this event didn't allow us to reject the null hypothesis, which  
185 is different from our study sample where we have shown a statistically significant performance level  
186 difference. Also, for the 5000 m and the marathon in class 12, respectively 73.60 % and 85.10 % of the  
187 thousand datasets created in these two events didn't allow us to reject the null hypothesis, which is different  
188 from our study sample where we have showed statistically significant performance level differences.

## 189 **Performance level**

### 190 Para swimming

191 The performance level analysis for men showed no statistical differences between PSCI and PSAI in mean  
1 192 performance among all sport classes in each event. (**Figure 2**). The performance level analysis for women  
2 193 showed no statistical differences between PSCI and PSAI in mean performance in 20 of 21 events (**Figure**  
3 194 **2**). A statistically significant difference was found for class 13 in the 400 m freestyle. In this event, the  
4 195 performance level was significantly higher for PSAI ( $p < 0.04$ ). Mean speed was  $1.29 \pm 0.11$  m.  $s^{-1}$  for PSCI  
5 196 and  $1.36 \pm 0.07$  m.  $s^{-1}$  for PSAI.

#### 6 197 Para athletics

8 198 The performance level analysis for men showed no statistical differences between PACI and PAAI in mean  
9 199 performance in 19 of 21 events (**Figure 2**). A statistically significant difference was found for class 12 in the  
10 200 5000 m. In this event, the performance level was significantly higher for PACI ( $p < 0.03$ ). Mean speed was  
11 201  $5.40 \pm 0.30$  m.  $s^{-1}$  for PACI and  $5.03 \pm 0.51$  m.  $s^{-1}$  for PSAI. A statistically significant difference was also  
12 202 found for class 12 in the marathon. In this event, the performance level was significantly higher for PACI ( $p$   
13 203  $< 0.04$ ). Mean speed was  $4.65 \pm 0.27$  m.  $s^{-1}$  for PACI and  $4.32 \pm 0.037$  m.  $s^{-1}$  for PAAI.

15 204 The performance level analysis for women showed no statistical differences between PACI and PAAI in  
16 205 mean performance in 20 of 21 events (**Figure 2**). A statistically significant difference was found for class 13  
17 206 in the 400 m. In this event, the performance level was significantly higher for PACI ( $p < 0.04$ ). Mean speed  
18 207 was  $6.43 \pm 0.54$  m.  $s^{-1}$  for PACI and  $5.92 \pm 0.72$  m.  $s^{-1}$  for PAAI.

20 208 **Age related performance.** In each event, the age-performance relationship displayed a similar pattern  
21 209 between the CI and AI groups in Para swimming and Para athletics. Performance increased progressively up  
22 210 to a peak and then decreased gradually. Based on the event, the EAPP were different between impairment  
23 211 classes and VI origin. The modelling parameters ( $a, b, c, d, f$ ), EAPP,  $R^2$  and the observed age at peak  
24 212 performance are available in *Table 1 – Supplementary Material*.

#### 25 213 Para swimming

27 214 The age-performance relationship analysis for females showed a statistically significant difference in mean  
28 215 EAPP for class 11 and 12 between PSCI and PSAI (**Figure 3**). For class 11, the mean EAPP were  $18.08 \pm$   
29 216  $0.50$  years for PSCI and  $23.05 \pm 1.36$  years for PSAI ( $p < 0.01$ ). For class 12, the mean EAPP were  $18.19 \pm$   
30 217  $0.52$  years for PSCI and  $21.20 \pm 3.11$  years for PSAI ( $p < 0.03$ ).

32 218 The age-performance relationship analysis for males showed a statistically significant difference in mean  
33 219 EAPP for class 11 and 12 between PSCI and PSAI (**Figure 3**). For class 11, the mean EAPP were  $20.51 \pm$   
34 220  $2.45$  years for PSCI and  $23.77 \pm 1.46$  years for PSAI ( $p < 0.03$ ). For class 12, the mean EAPP were  $22.62 \pm$   
35 221  $2.80$  years for PSCI and  $26.04 \pm 1.57$  years for PSAI ( $p < 0.05$ ).

37 222 In class 13 for both genders, the age-performance relationship analysis showed no statistical differences  
38 223 between in mean EAPP for PSCI and PSAI ( $p > 0.05$ ).

#### 39 224 Para athletics

41 225 The age-performance relationship analysis for males and females showed no statistical differences ( $p > 0.05$ )  
42 226 in mean EAPP for PACI and PAAI in each sport class. (**Figure 4**).

## 44 227 **Discussion**

46 228 This study is the first to provide an initial investigation into the relationship between the origin of the  
47 229 impairment and performance in Paralympic disciplines. Based on international performances data since 2009,  
48 230 it aimed to determine if the origin of VI was a performance factor in Para swimming and Para athletics. The  
49 231 main findings showed that: 1) Performance level is similar among all impairment classes in both disciplines  
50 232 (**Figure 1 & 2**). 2) Age at peak performance is reached at any earlier age for male and female PSCI in class  
51 233 11 and 12 in almost all events (**Figure 3**). The findings of this study through the quantitative analysis of  
52 234 performance in visual impaired PS and PA provides an initial response to the expert panel's queries in both  
53 235 disciplines (Allen et al., 2020; Ravensbergen et al., 2018).

54 236 **Performance level.** The first finding of this study was the similar performance level between CI and AI  
55 237 groups in both Para swimming and Para athletics. Based on our data, the VI origin does not induce a difference  
56 238 in race performance between swimmers and track and field athletes with a congenital VI and an acquired VI.  
57 239 This result rejects our initial hypothesis that swimmer and track and field athlete with acquired VI would  
58 240 perform better than swimmer and track and field athlete with congenital VI.

241 Para-swimming expert panel unanimously stated that a swimmer with a congenital impairment would be at a  
242 significant disadvantage against another swimmer with acquired impairment if the two swimmers had the  
243 same level of visual impairment. Main hypothesis was that having good vision in the early years of learning  
244 would allow the acquisition of general motor skills and would favour the learning of specific swimming  
245 techniques(Ravensbergen et al., 2018). Results of this study showed that, regardless of the impairment origin,  
246 Para swimmers did not show significantly different mean performances. Para Athletics expert panel noted  
247 that performance in running events would be impacted by age at onset of impairment, whether for athletes  
248 with partial or total blindness. Without reaching consensus, several scenarios emerged: i) athletes with a  
249 congenital impairment would already be adapted to their condition, which would give them an advantage  
250 over an athlete with an acquired impairment; ii) athletes with an acquired impairment might have had a better  
251 chance of acquiring fundamental motor skills at an early age; iii) if two athletes with a different origin of  
252 impairment had a different sporting background, they would not have an advantage(Allen et al., 2020). Based  
253 on our study, mean performance was not significantly different according to the impairment origin.

254 Performance in swimming and athletics is related to a multitude of physiological, psychological,  
255 biomechanical and environmental parameters. It is well known that technical skills are important performance  
256 related factors, especially in swimming(Koopmann et al., 2020). As mention in introduction, athletes with AI  
257 could beneficiate from learning specific skills before acquiring a VI and also could be able to transfer general  
258 cognitive skills acquired in early sport experience(Dehghansai et al., 2017). However, an athlete who has  
259 been visually impaired since birth is likely to develop adaptations by compensatory mechanisms in  
260 visuospatial processes(Monegato et al., 2007) and also somatosensory and vestibular systems(Schwesig et  
261 al., 2011). To reach a same level of performance, it could take more times for an athlete with CI to develop  
262 specific technical skills compared to an athlete with AI.

263 **Age related performance.** The interest in understanding if the VI origin is a performance related factor led  
264 to us studying the pathways of performance. This is of interest as the developmental models of athletes with  
265 impairments could be different according to the age at which they acquire their impairment (Dehghansai &  
266 Baker, 2020). Based on international performance data since 2009, this study showed that PSCI reach their  
267 peak performance at a younger age than PSAI in classes 11 and 12. This result is in accordance with the  
268 research of Dehghansai & al. They found that Canadian wheelchair basketball players with acquired  
269 disabilities reached a majority of milestones career at later ages with also more variability than players with  
270 congenital disabilities(Dehghansai et al., 2017).

271 The observed pattern for the age-performance relationship was similar between PA and PS. It also followed  
272 a similar trend to previous studies on wheelchair athletes in both PA (Schipman et al., 2019) and PS (Hogarth  
273 et al., 2020). The estimated age at peak performance varied depending on the discipline, impairment  
274 classification, event, sex, and especially VI origin. Age-related changes in performance are partly due to both  
275 physical and psychological changes. Moreover, differences in the age of peak performance could be  
276 influenced by the psycho-physiological demand of the discipline, the specific event (e.g., the  
277 distance)(Mcgregor et al., 2014; Schipman et al., 2019), and the impairment severity(Burkett et al., 2018;  
278 Hogarth et al., 2020; Schipman et al., 2019).

279 The scientific literature on performance pathways in Paralympic disciplines is limited. Impairment type and  
280 classification are initial factors to consider in talent identification. But several socio-environmental,  
281 demographical, physiological, psychological and political variables will also influence the developmental  
282 process of each Paralympic athlete(Dehghansai et al., 2021). Our result showed that impairment origin is also  
283 an important factor that have to be incorporated into a para-sport development model. Understanding the  
284 similarities and differences between VI origins, such as the age at peak performance, would allow a better  
285 individualization of swimmers' training plans and goals. It could also provide additional information on  
286 athletes' potentials and support in detection of young athletes. We found no difference in class 13 for both  
287 male and female PS. Further, there was no difference in estimated age at peak performance between  
288 individuals with a CI or an AI in Para athletics in any impairment class. A statistical fluctuation due to limited  
289 data and the age distribution could explain these results. Indeed, the age distribution of our sample was highly  
290 variable by impairment classes and gender in each discipline (*Figure 1 and 2 – Supplementary Material*).  
291 However, they could also be explained by the specific requirements of Para athletics compared to Para  
292 swimming. Para swimming is consider as an good activity for people with VI because of its few barriers and  
293 the possibility to move freely without obstacles(Lieberman, 2002) and because it is considered to have a low  
294 injury risk (Silva et al., 2013). It could be hypothesized that people with a CI are more likely to practice  
295 swimming from a young age, which could lead them towards a Para swimming career. Further, in Para  
296 athletics, VI athletes in class 11 and 12 have to/can be assisted by a guide. If young athletes struggle to find  
297 guide, it could limit their participation. These differences between Para swimming and Para athletics highlight

298 the need for more research in this area to develop a classification system that is specific to the considered  
299 discipline.

300 Furthermore, our performance level analysis in Para swimming and Para athletics also allows us to observe a  
301 similar performance level between class 12 and 13 (**Figure 2**) and affirm the findings from previous studies  
302 that demonstrated a similar performance level between the two classes for some events (Chun et al., 2019;  
303 Daly et al., 2009; Malone et al., 2001). These results highlight the need for research in this area and for a  
304 discussion on the effectiveness of the classification system for PS and PA with a VI in class 12 and 13.

305 **Limits.** There are several limitations in this work that need to be acknowledged. The first limit was the amount  
306 of data available. Only data between 2009 and 2019 was included. A larger sample with a greater number of  
307 events would have allowed us to be more conclusive in our results. Additionally, a significant proportion of  
308 data on swimmers' impairment origins was missing. This information is a matter of data protection and is  
309 therefore difficult to acquire for all athletes. However, we tested the robustness of our study sample against  
310 missing data using data imputation methods. Indeed, analysing the performance level between the CI and AI  
311 groups with the MI group randomly distributed didn't change the results as a similar performance level was  
312 noted between the CI and AI groups. It should be noted that the decision to compare performance on each  
313 event and in each class could induce a type 1 error in which the null hypothesis is incorrectly rejected. Finally,  
314 the lack of data ( $n < 10$ ) after 30 years for PACI and PAAI didn't allow us to model the age-performance  
315 relationship in 100m breaststroke (class 12) in Para swimming and in marathon (class 11,12,13), 800m (class  
316 12,13), 1500m (class 12,13) and long jump (class 11,13) in para athletics.

317 **Perspectives.** Further research into the influence of VI origin on Paralympic performance should be  
318 conducted. It would be interesting to focus on individual performance rather than performance level.  
319 Understanding the differences between the progression of eyesight loss (immediate or gradual) for athletes  
320 with an AI athlete would also be valuable. Expanding this study to other sport classes and other Paralympic  
321 disciplines will provide additional information in the investigation of differences between athletes with CI  
322 and AD.

## 323 **Conclusion**

324 This study revealed that VI origin can influence the progression pathway. PS with congenital VI reach an  
325 earlier age at peak performance in class 11 and 12. A similar performance level was highlighted in both  
326 disciplines for each sport class. These results could allow a better individualization of athlete support and  
327 provide additional information about each swimmer's potential. Further studies should be conducted to  
328 corroborate these observations and questions the necessity to add the impairment origin in the classification  
329 system.

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335 of the IPC website.

336 **Conflicts of interest statement.** The authors declare that the research was conducted in the absence of any  
337 commercial or financial relationships that could be construed as a potential conflict of interest.

## 338 **Availability of data and materials**

339 Available on request.

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441 **TABLES:**

442 Table 1: Visual impairment rules and regulations in Para swimming and Para athletics

Sport Class	Rules and regulation		Sport	
	Visual acuity (LogMar scale)	Visual field	Para swimming	Para athletics
11	Less than 2.60	/	Athletes must wear opaque goggles and have a tapper	Athletes must wear opaque glasses and run with a guide
12	Range from 1.50 to 2.60 (inclusive)	Constricted to a diameter of less than 10 degrees	/	Athletes have the option to run with a guide
13	Range from 1 to 1.40 (inclusive)	Constricted to a diameter of less than 40 degrees	/	/

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444 Table 2: Number of races by impairment sport classes and impairment origin groups among

445 Para swimmers and Para athletes male and female

Class	<i>Para swimming</i>			<i>Para athletics</i>		
	Male	Female	Total	Male	Female	Total
<b>Class 11</b>						
Congenital impairment	554	633	1187	367	222	589
Acquired impairment	1016	507	1523	1114	610	1724
Missing information	626	189	815	794	395	1189
<b>Class 12</b>						
Congenital impairment	503	526	1029	530	370	900
Acquired impairment	573	336	909	750	394	1144
Missing information	926	403	1329	1311	471	1782
<b>Class 13</b>						
Congenital impairment	609	737	1346	472	259	731
Acquired impairment	566	428	994	1152	273	1425
Missing information	1007	480	1487	1168	290	1458
<b>TOTAL</b>						
Congenital impairment	1666	1896	3562	1369	851	2220
Acquired impairment	2155	1271	3426	3016	1277	4293
Missing information	2559	1072	3631	3273	1156	4429

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447 Table 3: Mean (%) of the thousand datasets (created for the missing data imputation method) with similar performance level between

448 Congenital impairment and Acquired impairment groups in Para swimming and Para athletics (p > 0.05)

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	Para swimming							Para athletics					
	Females			Males				Females			Males		
Events	Class 11	Class 12	Class 13	Class 11	Class 12	Class 13	Events	Class 11	Class 12	Class 13	Class 11	Class 12	Class 13
100m	97,4	99,4	99,8	99,6	98,0	95,8	100m	99,0	93,6	97,1	98,7	98,9	98,0
400m	99,8	99,2	99,8	99,7	99,0	98,5	400m	98,5	94,1	77,7	99,1	95,8	93,0
800m	70,7	99,7	76,6	100,0	98,3	99,1	800m	98,4	99,7	99,3	94,3	89,7	94,3
1500m	85,2	97,5	99,9	100,0	97,4	99,3	1500m	99,0	99,4	91,5	97,1	82,1	99,0
5000m	100,0	96,5	99,2	100,0	91,8	93,6	5000m	99,5	95,1	96,7	97,3	73,6	96,9
Marathon	100,0	98,4	98,7	99,3	94,1	99,0	Marathon	97,3	100,0	NA	96,5	85,1	100,0
Long Jump	97,6	96,4	98,8	98,7	99,1	99,2	Long Jump	99,6	99,7	NA	94,7	98,4	97,9

450 **FIGURES:**

1 451 FIGURE 1: Relative performance (in percentage (%) of the best performance for each event) in Congenital  
2 452 impairment, Acquired impairment and Missing information groups for each sport class in Para swimming and  
3 453 Para athletics events.

4 454 \*: Indicate a significant mean relative performance difference ( $p < 0,05$ ) with the two others groups

6 455 \*\*\*: Indicate a significant mean relative performance difference ( $p < 0,001$ ) with the two others groups

8 456 FIGURE 2: Performance level (mean  $\pm$  sd) in each event for each sport class in Para swimming and Para athletics.  
9 457 Performance is expressed as speed ( $m.s^{-1}$ ) or distance (m) for long jump.

10 458 \*: Indicate a significant mean performance difference between Congenital impairment and Acquired impairment  
11 459 ( $p < 0.05$ )

13 460 FIGURE 3: Age related performance modelling in Para swimming by visual impairment origin (Congenital  
14 461 impairment and Acquired impairment) in 100 m freestyle - class 11, 50 m freestyle - class 12 and 200 m Individual  
15 462 Medley (I.M) - class 13.

16 463 FIGURE 4: Age related performance modelling in Para athletics by visual impairment origin (Congenital  
17 464 impairment and Acquired impairment) in 100 m (male) and 200 m (female) - class 11, 400 m (male) and 100 m  
18 465 (female) - class 12, 1500 m (male) and 400 m (female) - class 13

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Figure 1

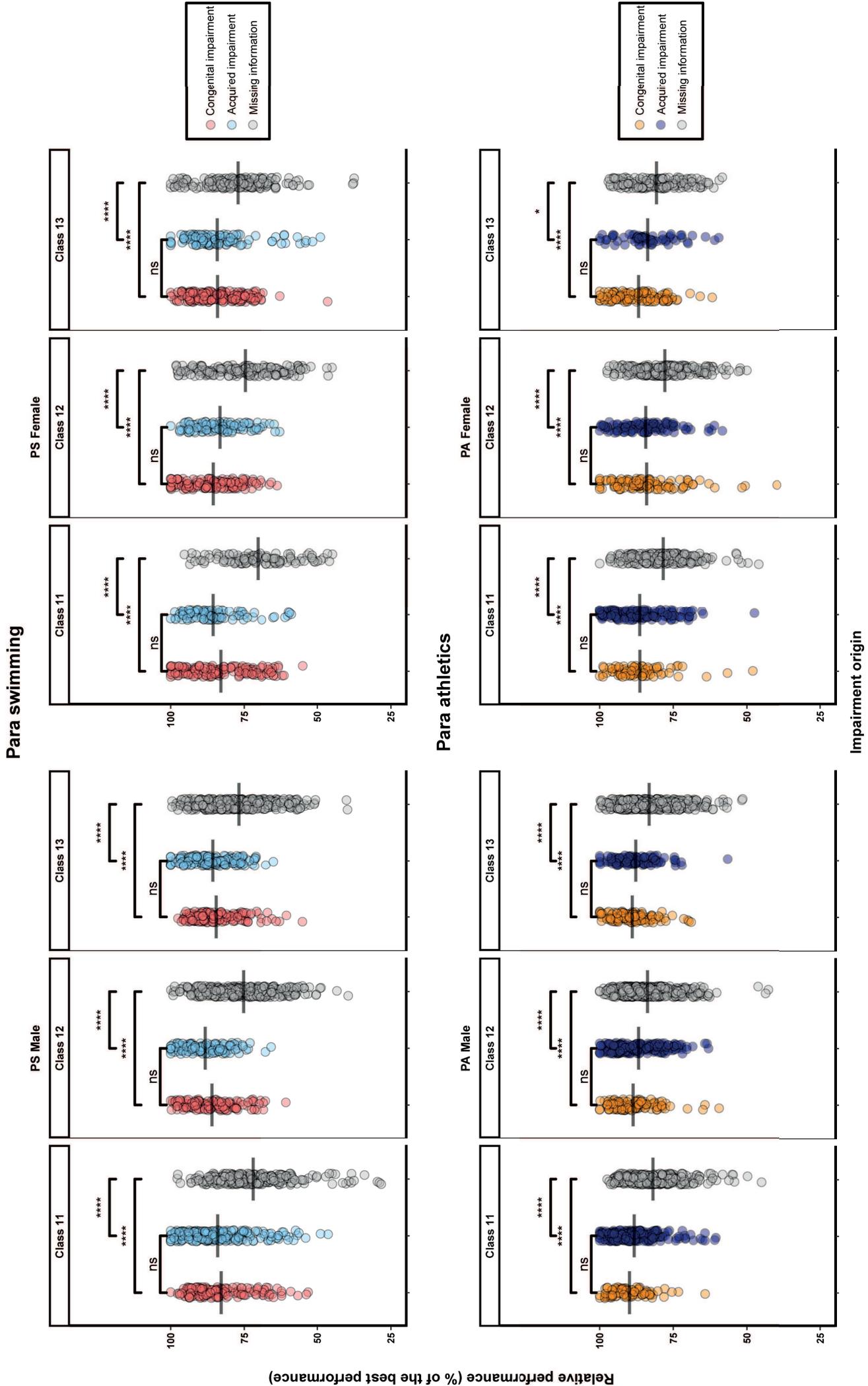


Figure 2

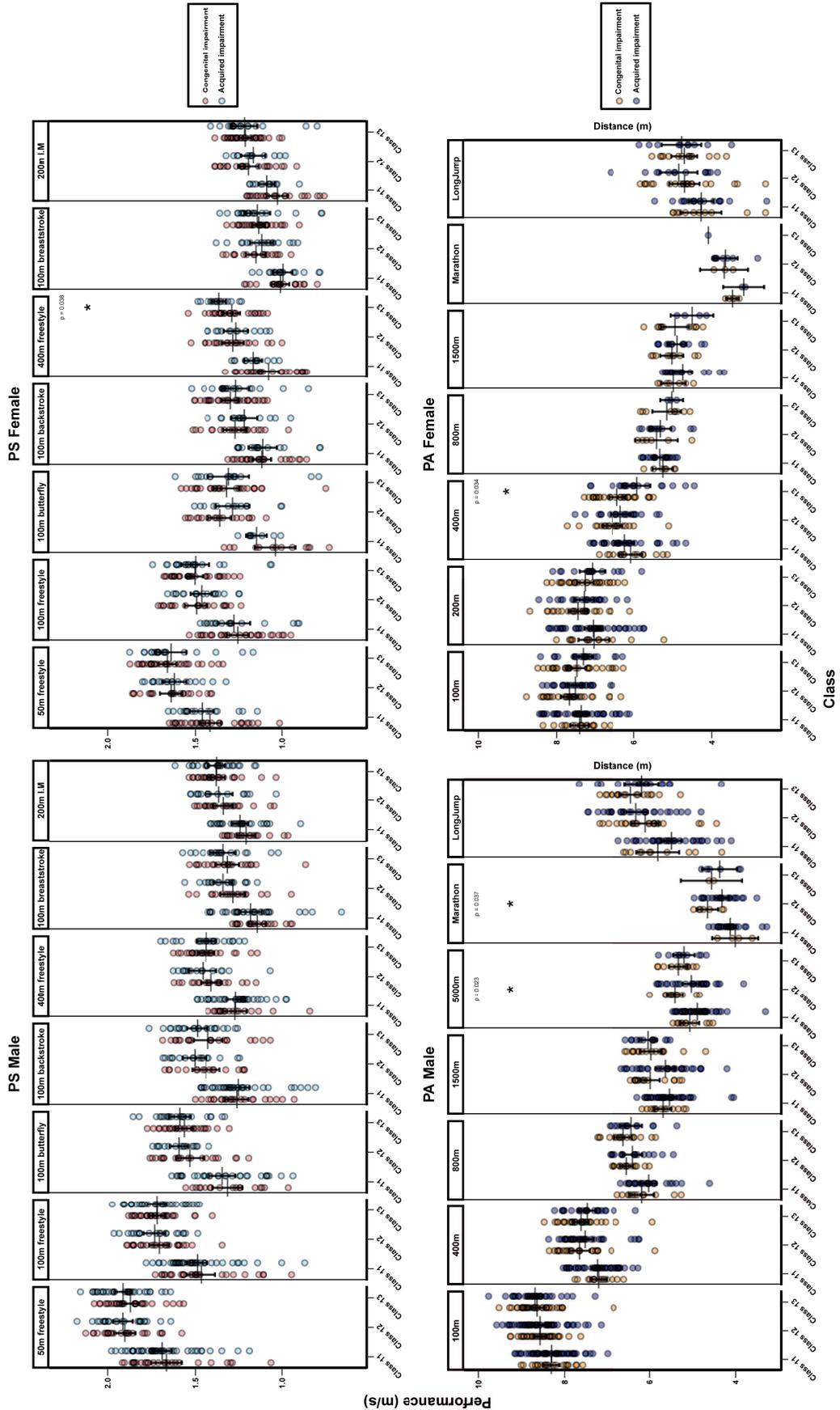


Figure 3

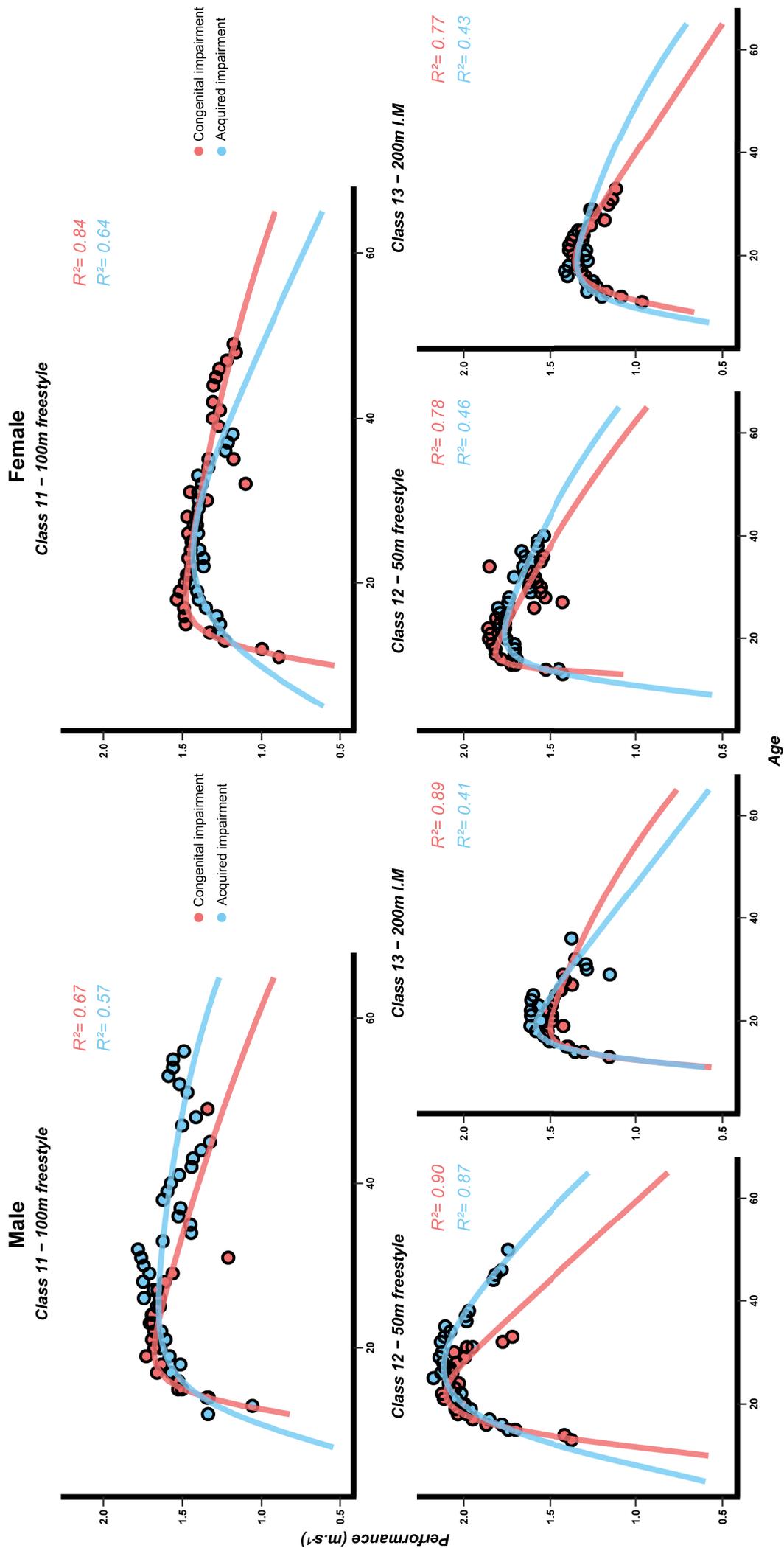


Figure 4

