



HAL
open science

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

Bryan Le Toquin, Julien Schipman, Quentin de Laroche Lambert, Guillaume Saulière, Stephanie Duncombe, Jean-François Toussaint

► To cite this version:

Bryan Le Toquin, Julien Schipman, Quentin de Laroche Lambert, Guillaume Saulière, Stephanie Duncombe, et al.. Is the visual impairment origin a performance factor? Analysis of international-level para swimmers and para athletes. *Journal of Sports Sciences*, 2022, 40 (5), pp.489-497. 10.1080/02640414.2021.1999618 . hal-03626716

HAL Id: hal-03626716

<https://insep.hal.science/hal-03626716>

Submitted on 31 Mar 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

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

3 Le Toquin, Bryan¹, Schipman, Julien^{1,2}, De Laroche Lambert, Quentin^{1,3} Saulière, Guillaume¹, Duncombe,
4 Stephanie⁴ and Toussaint, Jean-François^{1,2,5}

5 ¹*Institut de Recherche bio-Médicale et d'Épidémiologie du Sport (IRMES), EA 7329, Institut National du*
6 *Sport, de l'Expertise et de la Performance (INSEP)*

7 ²*Université de Paris, Paris, France*

8 ³*Université de Dijon, Dijon, France*

9 ⁴*School of Human Movement and Nutrition Sciences, University of Queensland, Australia*

10 ⁵*Centre d'Investigations en Médecine du Sport (CIMS), Hôtel-Dieu, Assistance Publique - Hôpitaux de Paris,*
11 *Paris, France*

12 Word count: 4786

13 Corresponding author: Bryan Le Toquin,

14 Institut de Recherche bio-Médicale et d'Épidémiologie du Sport (IRMES), EA 7329, Institut National du
15 Sport, de l'Expertise et de la Performance (INSEP), Paris, France

16 Postal Adress : 11 Avenue du Tremblay, 75012 Paris

17 Mail : bryan.letouquin@insep.fr

18 Tel : +0033141744124

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

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**

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

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. 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 ± 0.11 m. s^{-1} for PSCI
5 196 and 1.36 ± 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 ± 0.30 m. s^{-1} for PACI and 5.03 ± 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 ± 0.27 m. s^{-1} for PACI and 4.32 ± 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 ± 0.54 m. s^{-1} for PACI and 5.92 ± 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 ± 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 ± 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 ± 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 ± 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.

330 **Acknowledgments.** This work was supported by the French Ministry of Sports and the French disabled sports
331 federation (FFH). It was realized within the framework of the priority research program "Sport of very high
332 performance" PARAPERF supported by the French National Research Agency. The authors thank the INSEP
333 teams, the French National Sport Agency (ANS), the French disabled sports federation (FFH), and the French
334 Paralympic and Sports Committee (CPSF) for their full support. In addition, the authors thank all the curators
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.

340 **References**

341 Allen, P. M., Dolan, R., Croxall, H., Ravensbergen, R. H. J. C., Brooks, A., Zenk, F., & Mann, D. L.
342 (2020). Evidence-based Classification in Track Athletics for Athletes with a Vision Impairment: A

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
- 343 Delphi Study. *Optometry and Vision Science: Official Publication of the American Academy of*
344 *Optometry*, 97(11), 984–994. <https://doi.org/10.1097/OPX.0000000000001600>
- 345 Ashford, D., Bennett, S., & Davids, K. (2006). Observational Modeling Effects for Movement Dynamics
346 and Movement Outcome Measures Across Differing Task Constraints: A Meta-Analysis. *Journal*
347 *of Motor Behavior*, 38, 185–205. <https://doi.org/10.3200/JMBR.38.3.185-205>
- 348 Berthelot, G., Bar-Hen, A., Marck, A., Foulonneau, V., Douady, S., Noirez, P., Zablocki-Thomas, P.,
349 Antero, J., Carter, P., Meglio, J.-M., & Toussaint, J.-F. (2019). An integrative modeling approach
350 to the age-performance relationship in mammals at the cellular scale. *Scientific Reports*, 9.
351 <https://doi.org/10.1038/s41598-018-36707-3>
- 352 Berthelot, G., Johnson, S., Noirez, P., Antero, J., Marck, A., Desgorces, F.-D., Pifferi, F., Carter, P. A.,
353 Spedding, M., Manoux, A. S., & Toussaint, J.-F. (2019). The age-performance relationship in the
354 general population and strategies to delay age related decline in performance. *Archives of Public*
355 *Health*, 77(1), 51. <https://doi.org/10.1186/s13690-019-0375-8>
- 356 Berthelot, G., Len, S., Hellard, P., Tafflet, M., Guillaume, M., Vollmer, J.-C., Gager, B., Quinquis, L.,
357 Marc, A., & Toussaint, J.-F. (2012). Exponential growth combined with exponential decline
358 explains lifetime performance evolution in individual and human species. *Age (Dordrecht,*
359 *Netherlands)*, 34(4), 1001–1009. <https://doi.org/10.1007/s11357-011-9274-9>
- 360 Bouchard, D., & Tetreault, S. (2000). The Motor Development of Sighted Children and Children with
361 Moderate Low Vision Aged 8-13. *Journal of Visual Impairment & Blindness*, 94(9), 564–573.
- 362 Burkett, B., Payton, C., Van de Vliet, P., Jarvis, H., Daly, D., Mehrkuehler, C., Kilian, M., & Hogarth, L.
363 (2018). Performance Characteristics of Para Swimmers: How Effective Is the Swimming
364 Classification System? *Physical Medicine and Rehabilitation Clinics of North America*, 29, 333–
365 346. <https://doi.org/10.1016/j.pmr.2018.01.011>
- 366 Chun, R., Massof, R. W., Bradley, C., Allen, P., Ravensbergen, R., & Mann, D. (2019). Effects of visual
367 acuity loss on running performance among visually impaired Paralympic athletes. *Investigative*
368 *Ophthalmology & Visual Science*, 60(9), 1043–1043.
- 369 Daly, D., Malone, L., Burkett, B., Gabrys, T., & Satkunsienė, D. (2009). Is sight the main deterrent to race
370 performance in visually impaired competitive swimmers? *Facta Universitatis - Series: Physical*
371 *Education and Sport 1451-740X*, 7, 1–15.

- 372 Dehghansai, N., & Baker, J. (2020). Searching for Paralympians: Characteristics of Participants Attending
1
2 373 “Search” Events. *Adapted Physical Activity Quarterly: APAQ*, 37(1), 129–138.
3
4 374 <https://doi.org/10.1123/apaq.2019-0071>
5
- 6 375 Dehghansai, N., Lemez, S., Wattie, N., & Baker, J. (2017). Training and development of Canadian
7
8 376 wheelchair basketball players. *European Journal of Sport Science*, 17.
9
10 377 <https://doi.org/10.1080/17461391.2016.1276636>
11
- 12 378 Dehghansai, N., Pinder, R., & Baker, J. (2021). “Looking for a Golden Needle in the Haystack”:
13
14 379 Perspectives on Talent Identification and Development in Paralympic Sport. *Frontiers in Sports*
15
16 380 *and Active Living*, 3. <https://doi.org/10.3389/fspor.2021.635977>
17
- 18 381 Hodges, N., & Williams, A. (2007). Current status of observational learning research and the role of
19
20 382 demonstrations in sport. *Journal of Sports Sciences*, 25, 495–496.
21
22 383 <https://doi.org/10.1080/02640410600946753>
23
- 24 384 Hogarth, L., Nicholson, V., Payton, C., & Burkett, B. (2020). Modelling the age- related trajectory of
25
26 385 performance in Para swimmers with physical, vision and intellectual impairment. *Scandinavian*
27
28 386 *Journal of Medicine & Science in Sports*. <https://doi.org/10.1111/sms.13910>
29
- 30 387 Koopmann, T., Faber, I., Baker, J., & Schorer, J. (2020). Assessing Technical Skills in Talented Youth
31
32 388 Athletes: A Systematic Review. *Sports Medicine*, 50. <https://doi.org/10.1007/s40279-020-01299-4>
33
- 34 389 Lieberman, L. (2002). Fitness for Individuals Who Are Visually Impaired or Deafblind. *Rehabilitation and*
35
36 390 *Education for Blindness and Visual Impairment*.
37
- 38 391 Malone, L. A., Sanders, R. H., Schiltz, J. H., & Steadward, R. D. (2001). Effects of visual impairment on
39
40 392 stroke parameters in Paralympic swimmers. *Medicine and Science in Sports and Exercise*, 33(12),
41
42 393 2098–2103. <https://doi.org/10.1097/00005768-200112000-00019>
43
- 44 394 Mann, D. L., & Ravensbergen, H. J. C. (2018). International Paralympic Committee (IPC) and International
45
46 395 Blind Sports Federation (IBSA) Joint Position Stand on the Sport-Specific Classification of
47
48 396 Athletes with Vision Impairment. *Sports Medicine (Auckland, N.z.)*, 48(9), 2011–2023.
49
50 397 <https://doi.org/10.1007/s40279-018-0949-6>
51
- 52 398 Marc, A., Sedeaud, A., Schipman, J., Saulière, G., & Toussaint, J.-F. (2018). Age and Performance from 10
53
54 399 Seconds to a 6-Days Race. *Journal of Athletic Enhancement*, 07. <https://doi.org/10.4172/2324->
55
56 400 9080.1000298
57
58
59
60
61
62
63
64
65

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
- 401 McGregor, R., Cameron-Smith, D., & Poppitt, S. (2014). It is not just muscle mass: A review of muscle
402 quality, composition and metabolism during ageing as determinants of muscle function and
403 mobility in later life. *Longevity & Healthspan*, 3, 9. <https://doi.org/10.1186/2046-2395-3-9>
- 404 Monegato, M., Cattaneo, Z., Pece, A., & Vecchi, T. (2007). Comparing the Effects of Congenital and Late
405 Visual Impairments on Visuospatial Mental Abilities. *Journal of Visual Impairment and Blindness*,
406 101, 278–295. <https://doi.org/10.1177/0145482X0710100503>
- 407 Patatas, J., Bosscher, V., & Legg, D. (2018). Understanding parasport: An analysis of the differences
408 between able-bodied and parasport from a sport policy perspective. *International Journal of Sport*
409 *Policy*, 10, 235–254. <https://doi.org/10.1080/19406940.2017.1359649>
- 410 Ravensbergen, H. J. C., Genee, A. D., & Mann, D. L. (2018). Expert Consensus to Guide the Classification
411 of Paralympic Swimmers With Vision Impairment: A Delphi Study. *Frontiers in Psychology*, 9.
412 <https://doi.org/10.3389/fpsyg.2018.01756>
- 413 Ravensbergen, Mann, & Kamper. (2016). Expert consensus statement to guide the evidence-based
414 classification of Paralympic athletes with vision impairment: A Delphi study. *British Journal of*
415 *Sports Medicine*, 50(7), 386–391. <https://doi.org/10.1136/bjsports-2015-095434>
- 416 Schipman, J., Gallo, P., Marc, A., Antero, J., Toussaint, J.-F., Sedeaud, A., & Marck, A. (2019). Age-
417 Related Changes in Para and Wheelchair Racing Athlete's Performances. *Frontiers in Physiology*,
418 10. <https://doi.org/10.3389/fphys.2019.00256>
- 419 Schwesig, R., Goldich, Y., Hahn, A., Müller, A., Kohen-Raz, R., Kluttig, A., & Morad, Y. (2011). Postural
420 control in subjects with visual impairment. *European Journal of Ophthalmology*, 21(3), 303–309.
421 <https://doi.org/10.5301/EJO.2010.5504>
- 422 Silva, M. M. e, Bilzon, J., Duarte, E., Gorla, J., & Vital, R. (2013). Sport Injuries in Elite Paralympic
423 Swimmers With Visual Impairment. *Journal of Athletic Training*, 48(4), 493–498.
424 <https://doi.org/10.4085/1062-6050-48.4.07>
- 425 Skaggs, S., & Hopper, C. (1996). Individuals with Visual Impairments: A Review of Psychomotor
426 Behavior. *Adapted Physical Activity Quarterly*, 13(1), 16–26. <https://doi.org/10.1123/apaq.13.1.16>
- 427 Tweedy, S., Mann, D., & Vanlandewijck, Y. (2016). Research needs for the development of evidence-based
428 systems of classification for physical, vision, and intellectual impairments: Handbook of Sports
429 Medicine and Science. In *Handbook of Sports Medicine and Science: Training and Coaching the*
430 *Paralympic Athlete* (pp. 122–149). <https://doi.org/10.1002/9781119045144.ch7>

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

431 Weiss, M. R., McCullagh, P., Smith, A. L., & Berlant, A. R. (1998). Observational learning and the fearful
432 child: Influence of peer models on swimming skill performance and psychological responses.
433 *Research Quarterly for Exercise and Sport*, 69(4), 380–394.
434 <https://doi.org/10.1080/02701367.1998.10607712>
435 Wesch, N., Law, B., & Hall, C. (2007). The Use of Observational Learning by Athletes. *Journal of Sport*
436 *Behavior*, 30, 219–231.
437 World Health Organization. (2019). *ICD-11: International Classification of Diseases 11th Revision*.
438 World Para Athletics. (2018). *World Para Athletics—Classification Rules and Regulations*.
439 World Para Swimming. (2018). *World Para Swimming—Rules and regulations 2018*.
440

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	/	/

443
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
Class 11						
Congenital impairment	554	633	1187	367	222	589
Acquired impairment	1016	507	1523	1114	610	1724
Missing information	626	189	815	794	395	1189
Class 12						
Congenital impairment	503	526	1029	530	370	900
Acquired impairment	573	336	909	750	394	1144
Missing information	926	403	1329	1311	471	1782
Class 13						
Congenital impairment	609	737	1346	472	259	731
Acquired impairment	566	428	994	1152	273	1425
Missing information	1007	480	1487	1168	290	1458
TOTAL						
Congenital impairment	1666	1896	3562	1369	851	2220
Acquired impairment	2155	1271	3426	3016	1277	4293
Missing information	2559	1072	3631	3273	1156	4429

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12
- 13
- 14
- 15
- 16
- 17
- 18
- 19
- 20
- 21
- 22
- 23
- 24
- 25
- 26
- 27
- 28
- 29
- 30
- 31
- 32
- 33
- 34
- 35
- 36
- 37
- 38
- 39
- 40
- 41
- 42
- 43
- 44
- 45
- 46
- 47
- 48
- 49
- 50
- 51
- 52
- 53
- 54
- 55
- 56
- 57
- 58
- 59
- 60
- 61
- 62
- 63
- 64
- 65

16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

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)

449

	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

5
6 455 ***: Indicate a significant mean relative performance difference ($p < 0,001$) with the two others groups

7
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 ($p < 0.05$)

12
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

19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

Figure 1

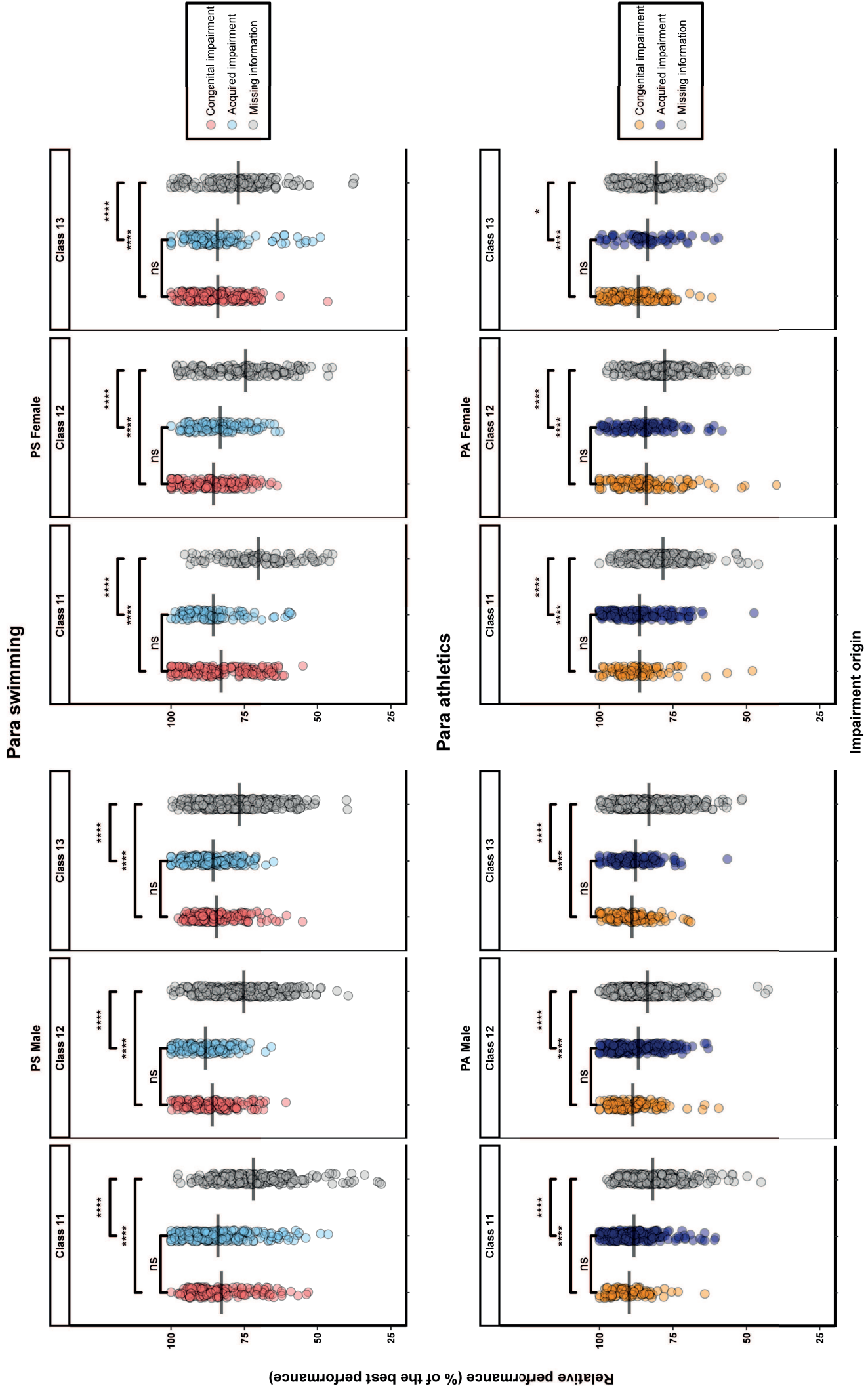


Figure 2

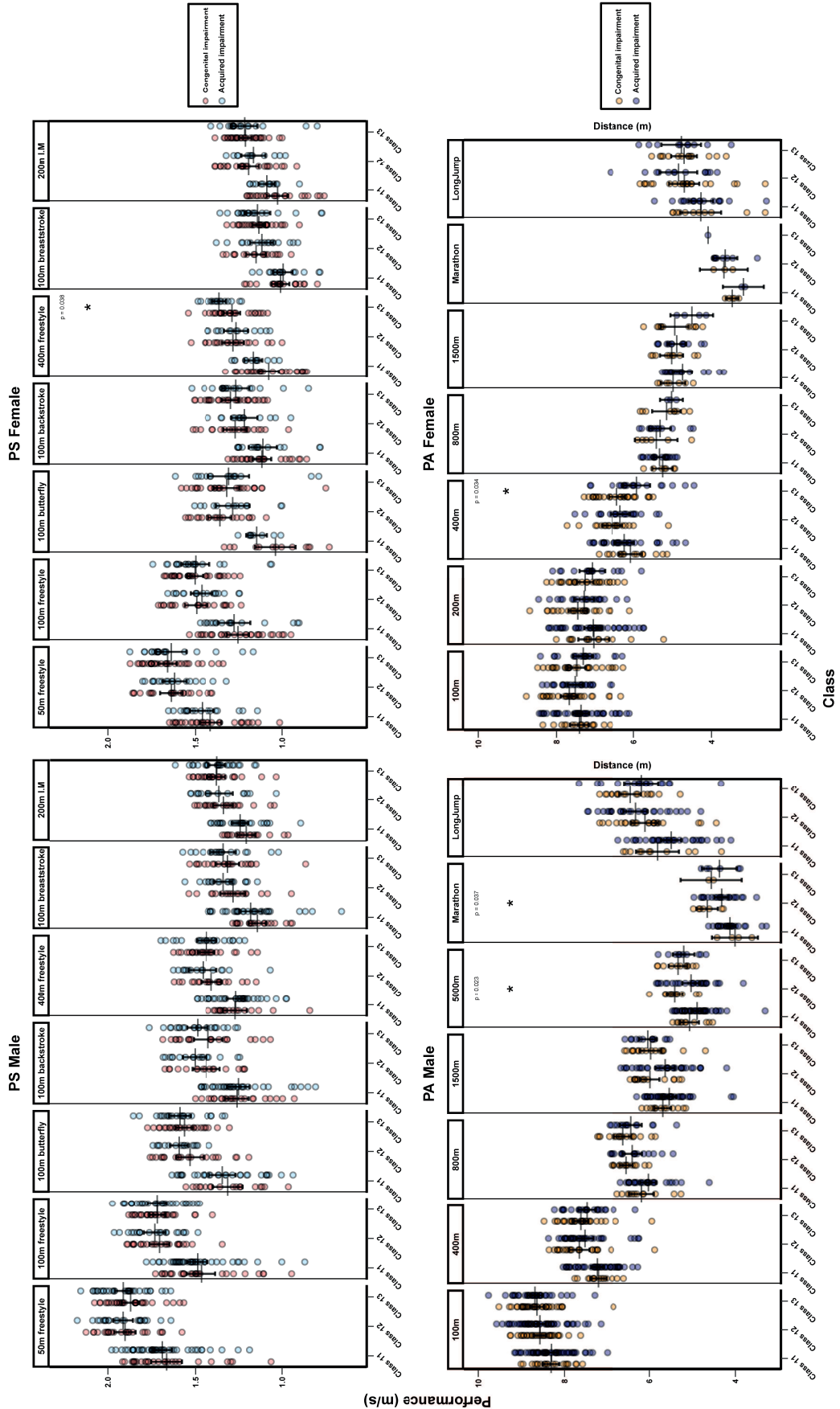


Figure 3

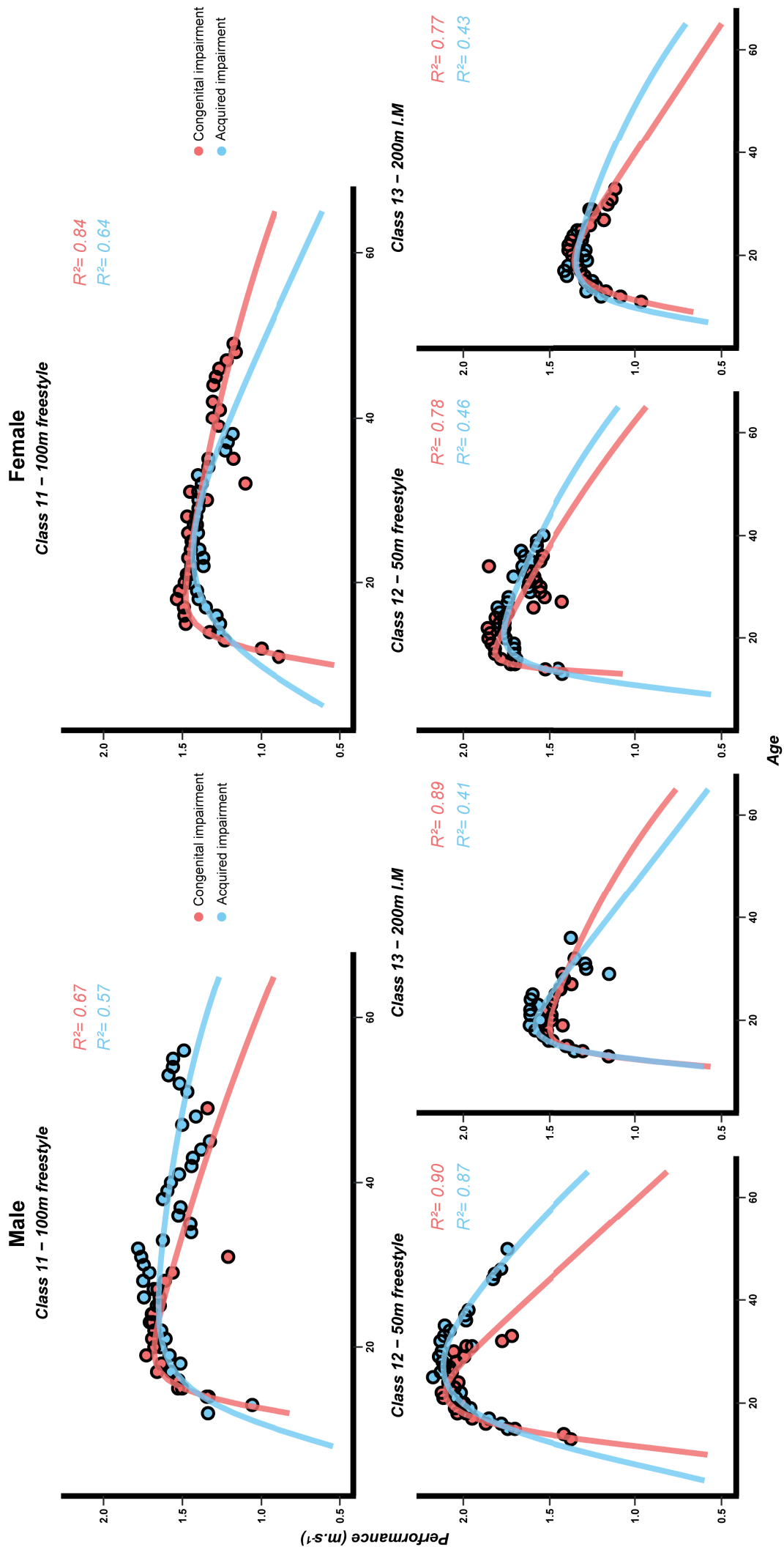


Figure 4

