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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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ABSTRACT

The aim of this study was to investigate the effect of congenital and acquired visual impairments on the international performance of Para swimmers and Para track and field athletes. We collected results from visually impaired Para athletes competing in Para swimming or Para athletic events at all IPC-labelled competitions between 2009 and 2019. The dataset contained 20,689 events results. Impairment origin was collected from the International Paralympic Committee (IPC) website. We separated impairment origin into two groups to distinguish those with a congenital impairment from those with an acquired impairment. In visual impairment sport classes (11–12-13), the performance level and the age performance relationship were investigated according to the impairment origin. In classes 11 and 12, peak performance was achieved earlier by male and female swimmers with a congenital impairment compared with those who had an acquired impairment ($p < 0.05$). No differences were present in class 13 or in any class in Para athletics ($p > 0.05$). A similar performance level was observed among the two sport disciplines for each class ($p > 0.05$). This study demonstrated that impairment origin can influence the performance pathway among visually impaired swimmers.

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KEYWORDS
Swimming; athletics; Paralympic; impairment origin; talent identification; para sport

Introduction

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

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

In order to assess the needs for a sport-specific and evidence-based VI classification system, two studies, based on a systematic interactive survey method address several key points for Para swimming and Para athletics classification systems. In both studies, expert panels unanimously agreed that the age at which a VI is acquired will impact the swimming and running performance and the technical skills acquisitions(Allen et al., 2020; H. J. C. Ravensbergen et al., 2018). Knowledge and scientific evidence about the difference between congenital and acquired impairment on sport performance is very limited. It is recognised that observational learning has an important role in motor and technical skills acquisition (Hodges & Williams, 2007; Weiss et al., 1998; Wesch et al., 2007). Also, observational learning effect and outcomes are known to be influenced by age(Ashford et al., 2006). The relationship

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Table 1. Visual impairment rules and regulations in para swimming and para athletics.

	Rules and regulation		Sport	
Sport Class	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	/	/

between the age at which the impairment is acquired and the time required for skill acquisition will depend on the specific complexity of the sport(Allen et al., 2020; H. J. C. Ravensbergen et al., 2018). The difficulty to use observational learning in training for athlete with VI could induce a longer time to acquire motor learning and specific skills (Mann & Ravensbergen, 2018; H. R. Ravensbergen et al., 2016). These observations highlight the need to investigate the age of the acquired VI and how it could influence performance. To our knowledge, no studies have been conducted comparing quantitatively the performance level between Paralympic athletes with a congenital impairment (CI) and an acquired impairment (AI).

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

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

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 programme. 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.s^{-1}), year of the event, last and first name, age (in years), sex, and impairment classification. A categorical variable "VI origin" with three 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 from 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. 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 for each event (j) and for each class(k) (Equation (1)). This method allowed us to compare intra-class performance by grouping all events.

$$RP_i(\%) = \frac{World\ record_{jk}}{Best\ individual\ performance_{jk}} * 100 \quad (1)$$

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 $m.s^{-1}$ and metres (m) for long jump event.

Missing data imputation

In order to minimise missing data (referred as MI group) bias, a missing data imputation method was implemented. We created 1000 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: number of missing data in each class and each event

p: 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 were 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 (Equation (2)) is based on an enhanced biological foundation (Berthelot, Bar-Hen et al., 2019). The formula of IMAP1 is:

$$P(t) = a \cdot e^{\frac{b}{c}(1-e^{-ct})} \cdot \left(1 - e^{d(t-f)}\right) \quad (2)$$

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

Statistical analysis

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

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

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

Ethics statement

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

Results

The Para swimming dataset contained 10,619 event times: 6380 events from 408 males; 4239 events from 227 females. The Para athletics dataset contained 10,942 event times: 7658 events from 1031 males; 3284 events from 447 females (Table 2).

Relative performance

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

Table 2. Number of races by impairment sport classes and impairment origin groups among para swimmers and para athletes male and female.

	Para swimming			Para athletics		
Class 11	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
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

Missing data imputation

In each sport class, the missing data imputation method also highlighted a similar performance level in both disciplines between CI and AI groups with the MI group individuals randomly distributed (Table 3). In Para swimming, for the 400 m freestyle, 76.60% of the thousand datasets created in this event didn't allow us to reject the null hypothesis, which is different from our study sample where we have shown a statistically significant performance-level difference. In Para athletics, for the 400 m, in class 13, 77.70% of the thousand datasets created in this event didn't allow us to reject the null hypothesis, which is different from our study sample where we have shown a statistically significant performance-level difference. Also, for the 5000 m and the marathon in class 12, respectively 73.60% and 85.10% of the 1000

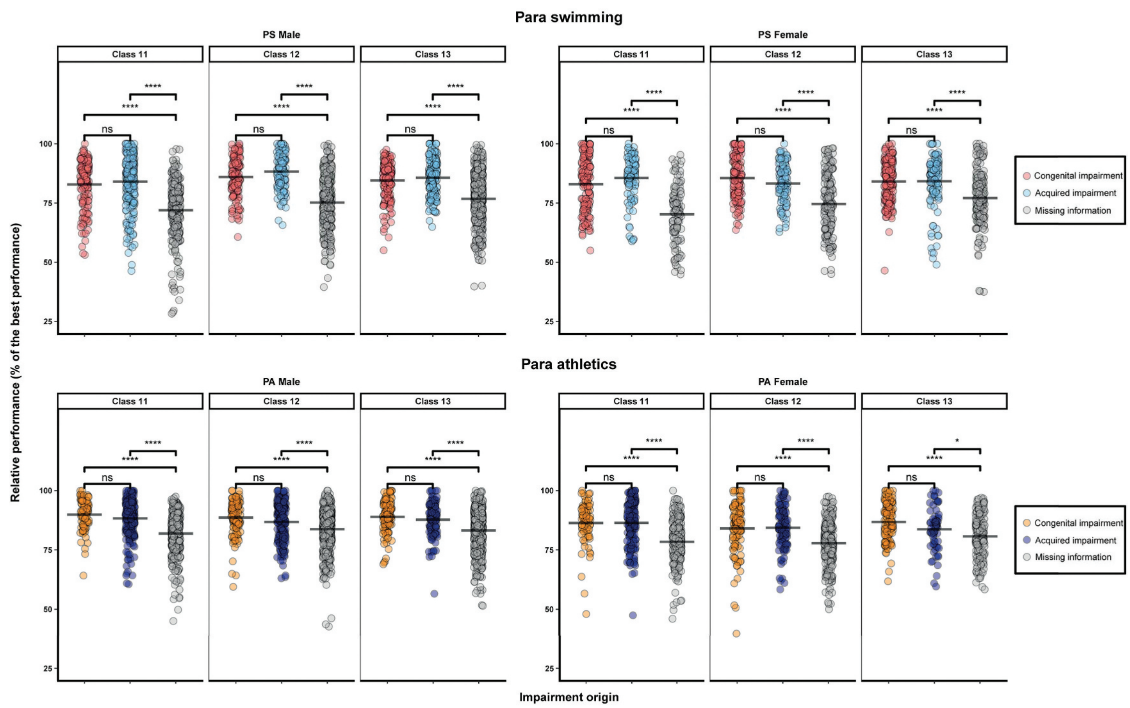

Figure 1. Relative performance (in percentage (%) of the best performance for each event) in congenital impairment, acquired impairment and missing information groups for each sport class in para swimming and para athletics events. *: Indicate a significant mean relative performance difference ($p < 0{,}05$) with the two others groups****: Indicate a significant mean relative performance difference ($p < 0{,}001$) with the two others groups

Table 3. Mean (%) of the thousand datasets (created for the missing data imputation method) with similar performance level between congenital impairment and acquired impairment groups in para swimming and para athletics ($p \geq 0.05$).

	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
50 m freestyle	97,4	99,4	99,8	99,6	98,0	95,8	100 m	99,0	93,6	97,1	98,7	98,9	98,0
100 m freestyle	99,8	99,2	99,8	99,7	99,0	98,5	400 m	98,5	94,1	77,7	99,1	95,8	93,0
400 m freestyle	70,7	99,7	76,6	100,0	98,3	99,1	800 m	98,4	99,7	99,3	94,3	89,7	94,3
100 m butterfly	85,2	97,5	99,9	100,0	97,4	99,3	1500 m	99,0	99,4	91,5	97,1	82,1	99,0
100 m backstroke	100,0	96,5	99,2	100,0	91,8	93,6	200 m (Females) / 5000 m (Males)	99,5	95,1	96,7	97,3	73,6	96,9
100 m breaststroke	100,0	98,4	98,7	99,3	94,1	99,0	Marathon	97,3	100,0	NA	96,5	85,1	100,0
200 m individual medley	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

datasets created in these two events didn't allow us to reject the null hypothesis, which is different from our study sample where we have showed statistically significant performance-level differences.

Performance level

Para swimming

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

Para athletics

The performance-level analysis for men showed no statistical differences between PACI and PAAI in mean performance in 19 of 21 events (Figure 2). A statistically significant difference was found for class 12 in the 5000 m. In this event, the performance level was significantly higher for PACI ($p < 0.03$). Mean speed was 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 found for class 12 in the marathon. In this event, the performance level was significantly higher for PACI ($p < 0.04$). Mean speed was 4.65 ± 0.27 m. s^{-1} for PACI and 4.32 ± 0.037 m. s^{-1} for PAAI.

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

Age related performance

In each event, the age-performance relationship displayed a similar pattern between the CI and AI groups in Para swimming and Para athletics. Performance increased progressively up to a peak and then decreased gradually. Based on the event, the EAPP was different between impairment classes and VI origin. The modelling parameters (*a, b, c, d, f*), EAPP, R^2 and the observed age at peak performance are available in Table S1 – *Supplementary Material*.

Para swimming

The age-performance relationship analysis for females showed a statistically significant difference in mean EAPP for class 11 and 12 between PSCI and PSAI (Figure 3). For class 11, the mean EAPP were 18.08 ± 0.50 years for PSCI and 23.05 ± 1.36 years for PSAI ($p < 0.01$). For class 12, the mean EAPP was 18.19 ± 0.52 years for PSCI and 21.20 ± 3.11 years for PSAI ($p < 0.03$).

The age-performance relationship analysis for males showed a statistically significant difference in mean EAPP for class 11 and 12 between PSCI and PSAI (Figure 3). For class 11, the mean EAPP was 20.51 ± 2.45 years for PSCI and 23.77 ± 1.46 years for PSAI ($p < 0.03$). For class 12, the mean EAPP was 22.62 ± 2.80 years for PSCI and 26.04 ± 1.57 years for PSAI ($p < 0.05$).

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

Para athletics

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

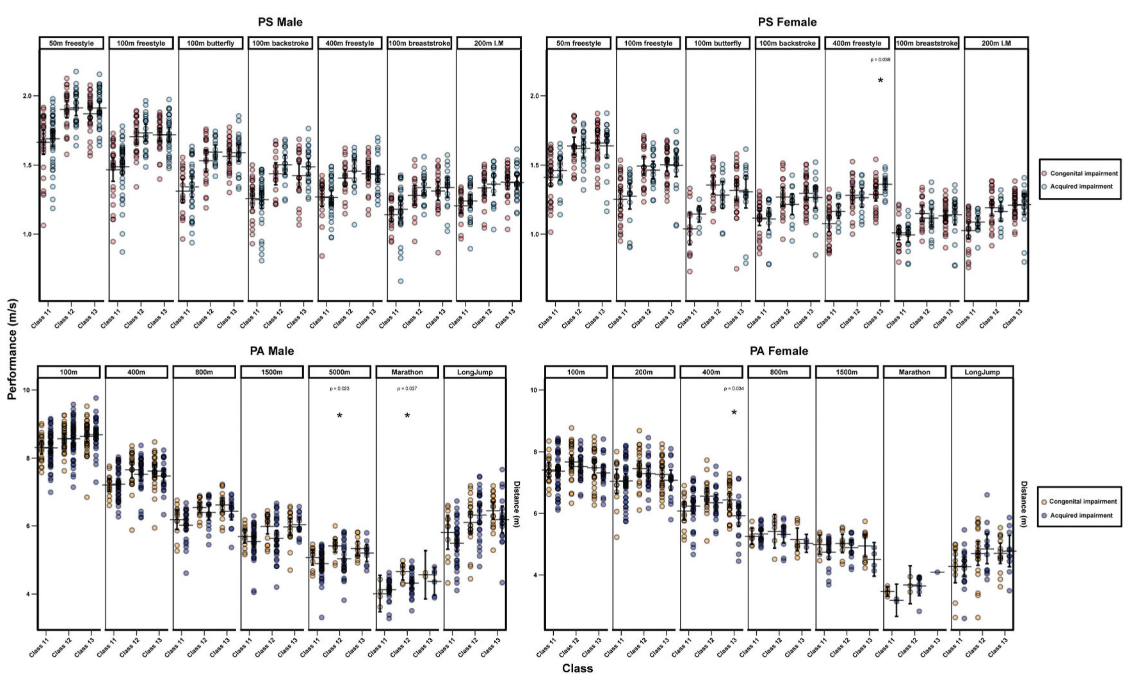

Figure 2. Performance level (mean ± sd) in each event for each sport class in para swimming and para athletics. Performance is expressed as speed ($m.s^{-1}$) or distance (m) for long jump. *: Indicate a significant mean performance difference between congenital impairment and acquired impairment ($p < 0.05$).

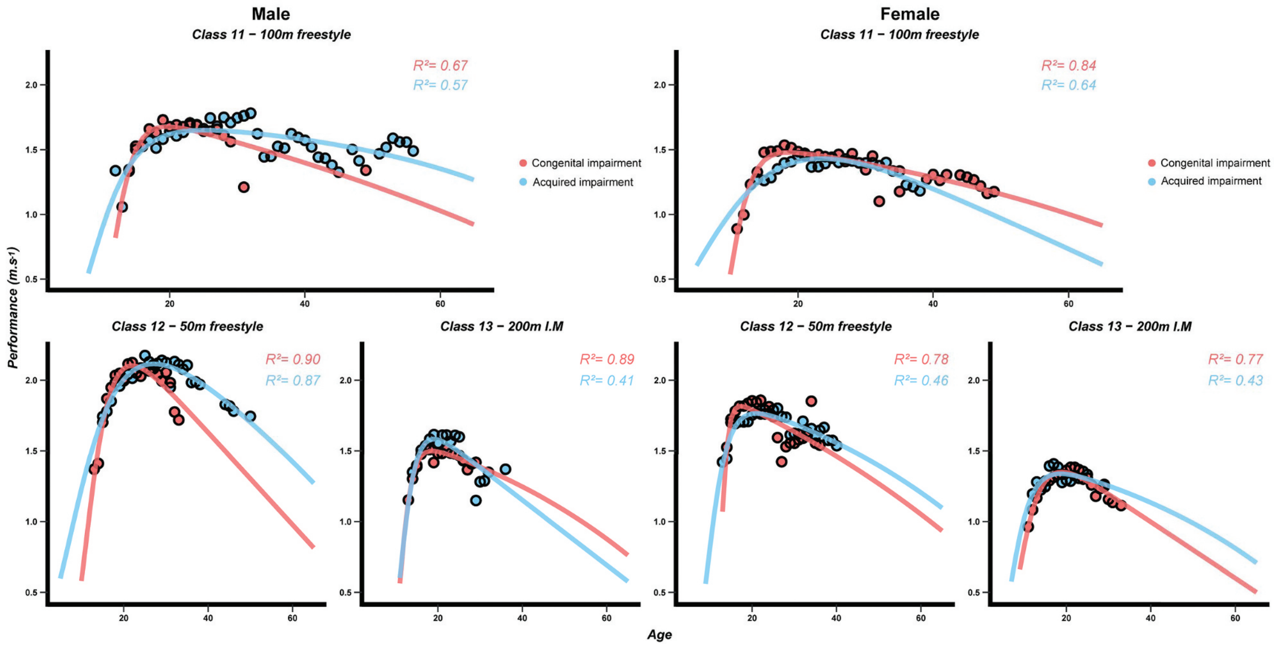

Figure 3. Age related performance modelling in para swimming by visual impairment origin (Congenital impairment and acquired impairment) in 100 m freestyle – class 11, 50 m freestyle – class 12 and 200 m individual medley (I.M) – class 13.

Discussion

This study is the first to provide an initial investigation into the relationship between the origin of the impairment and performance in Paralympic disciplines. Based on international performances data since 2009, it aimed to determine if the origin of VI was a performance factor in Para swimming and Para athletics. The main findings showed that: 1) Performance level is similar among all impairment classes in both disciplines (Figures 1–2). 2) Age at peak performance is reached at any earlier age for male and female PSCI in class 11 and 12 in almost all events (Figure 3).

The findings of this study through the quantitative analysis of performance in visual impaired PS and PA provide an initial response to the expert panel's queries in both disciplines(Allen et al., 2020; H. J. C. Ravensbergen et al., 2018).

Performance level

The first finding of this study was the similar performance level between CI and AI groups in both Para swimming and Para athletics. Based on our data, the VI origin does not induce a

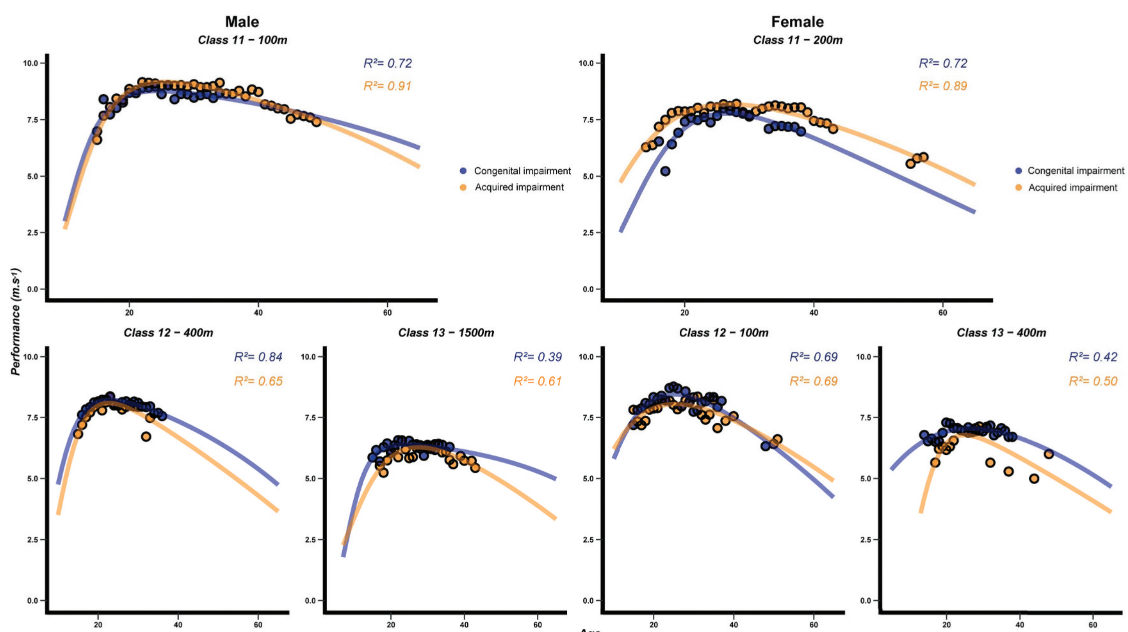

Figure 4. Age related performance modelling in para athletics by visual impairment origin (Congenital impairment and acquired impairment) in 100 m (male) and 200 m (female) – class 11, 400 m (male) and 100 m (female) – class 12, 1500 m (male) and 400 m (female) – class 13.

difference in race performance between swimmers and track and field athletes with a congenital VI and an acquired VI. This result rejects our initial hypothesis that swimmer and track and field athlete with acquired VI would perform better than swimmer and track and field athlete with congenital VI.

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

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

Age related performance

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

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

The scientific literature on performance pathways in Paralympic disciplines is limited. Impairment type and classification are initial factors to consider in talent identification. But several socio-environmental, demographical, physiological, psychological and political variables will also influence the developmental process of each Paralympic athlete (Dehghansai et al., 2021). Our result showed that impairment origin is also an important factor that has to be incorporated into a para-sport development model. Understanding the similarities and differences between VI origins, such as the age at peak performance, would allow a better individualisation of swimmers' training plans and goals. It could also provide additional information on athletes' potentials and support in detection of young athletes. We found no difference in class 13 for both male and female PS. Further, there was no difference in estimated age at peak performance between individuals with a CI or an AI in Para athletics in any impairment class. A statistical fluctuation due to limited data and the age distribution could explain these results. Indeed, the age distribution of our sample was highly variable by impairment classes and gender in each discipline (Figures S1 and S2 – Supplementary Material). However, they could also be explained by the specific requirements of Para athletics compared to Para swimming. Para swimming is considered as a good activity for people with VI because of its few barriers and the possibility to move freely without obstacles(Lieberman, 2002) and because it is considered to have a low injury risk (Silva et al., 2013). It could be hypothesised that people with a CI are more likely to practice swimming from a young age, which could lead them towards a Para swimming career. Further, in Para athletics, VI athletes in class 11 and 12 have to/can be assisted by a guide. If young athletes struggle to find guide, it could limit their participation. These differences between Para swimming and Para athletics highlight the need for more research in this area to develop a classification system that is specific to the considered discipline.

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

Limits

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

Perspectives

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

Conclusion

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

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Disclosure statement

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

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Availability of data and materials

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