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Abstract

BACKGROUND: The COVID 19 pandemic has greatly disrupted high performance sport and international competition. The aim of this study was to quantify the impact of the COVID-19 pandemic on the world's top 10 performances in Athletics and Swimming among non-disabled and Paralympic athletes.

METHODS: The results of the 10-best world performers in 66 Olympic events since 1891 and 255 Paralympic events since 2010 were collected. To quantify the performance trend, the slopes of the 4 years moving average were calculated and analyzed by time period. The distribution of performances (in % of the world record) by year was analyzed to compare the 2020 values to the ten previous years. The stability rate (athletes joining and leaving each year) since 2010 and the number of annual competitions events were also measured.

RESULTS: Over the study period, such declines in performance have only been observed during the two World Wars. In 2020, the level of performances has decreased significantly, corresponding to a 6 to 10 years setback. In 2020, the number of new athletes in the 10-best was significantly higher with a lower number of organized competitions.

CONCLUSIONS: The impact on the performances of the best international non-disabled and Para athletes has been considerable.

Key words: SPORT; PERFORMANCE; COVID-19; DECREASE; TOP10; OLYMPIC

Introduction

As of September, 20th 2021, more than 228 394 572 cases of COVID-19 have been recorded and 4 690 186 deaths are to be officially deplored [1]. This pandemic situation has generated varying levels of response. Societal restrictions and lockdown have caused several impacts on society. The global economic, environmental or health co-factors and collateral impacts of the pandemic are beginning to be assessed [2]. Regarding the sports field, the pandemic situation generated a sudden end to competitions [3] and a postponement of the Tokyo Olympic and Paralympic Games [4]. Months later, after setting up strict health protocols, the competitions were able to resume [5,6], without exposing athletes to an increased risk of contamination [7–9]. Meanwhile, different level of detraining [10,11] have been induced depending on each country's situation.

Among elite athletes, world records reflect maxima and temporal or absolute limits [12]. Secular trend based on 3263 world records, starting in 1896, revealed exponential progression toward a recent plateau [12,13]. This trend was also observed in sports with outdoor events exposed to non-standardized environments [14]. For more accurate measures, between 1891 and 2008, the annual performance of the ten best performers in more than 40 000 performances from 36 track and field and 34 swimming events were scrutinized [15]. Progressions were observed until a major stagnation since 1988 [15]. For swimming and running, several studies highlighted progression and stagnation of world records for female and male [13,16–18]. Exceptional performances are limited by physiological and genetic conditions, economic and environmental contexts and a participant population mostly consisting of athletes with optimized traits [13]. For Paralympic athletes, according to some disciplines, events and classifications, performance has increased slightly or not significantly over the past few years in Track & Field [19,20] and Para swimming [21]. An overall trend for improved Paralympic sprint performances in athletes with lower-limb

amputations since 1992 to 2012 was observed with a consequent role played by running-specific prostheses [22]. Best performances are also subject to an Olympic and Paralympic periodicity with an important increase during the months preceding the Games and a decrease the following year [15,21,23,24]. For Olympic and Paralympic athletes, major historical events may possibly alter both the organization of international competitions and the development of morphologies [25] and physical performance [13].

At the individual scale, a deconditioning was observed during lockdown associated with an increase in resting heart rate and a decrease in self-reported well-being [10]. Aerobic abilities and endurance capacity have also decreased in adolescent [11] and adult elite players [26]. For professional soccer players, prolonged abstinence from training and competitions induced by lockdown engaged athletes in a detraining situation [27]. In professional cyclists, a large reduction in physical tests as the best 5-minute and best 20-minute performance has been observed with 1% to 19% losses [28]. Significant reduction in physical fitness of international kickboxers has also been measured [29]. Even in para-athletes, time spent engaging in sedentary screen time activities increased during the COVID-19 pandemic, but with different capabilities of resilience [30]. Paralympic athletes perceived higher negative impact in their training and performance by the lockdown than Olympic athletes[31]. The lockdown has already altered athletes' condition and well-being as well as behavioral, psychological, and training patterns [32], but no study has measured the pandemic impact on high-level performances.

The aim of this study was to quantify the impact of the COVID-19 pandemic on the world's best performances in Track & Field and Swimming among non-disabled and Paralympic athletes.

Methods

Data collection

We collected the single best result of the 10-best world performers every year from two quantifiable sports in 66 major Olympic events and 255 major Paralympic events: 38 Track & Field (T&F) events over the modern Olympic era (1891–2020) and 28 swimming events over the 1963–2020 period; 168 Paralympic T&F events between 2010–2020 and 139 Paralympic swimming events over the 2010–2020 period.

The Olympic and Paralympic events collected were in T&F for the race events: 100m, ~~200m,~~ 100m hurdles, 110m hurdles, 200m, 400m, 400m hurldes, 800m, 1500m, 3000m steeple, 5000m, 10000m and Marathon; for the jump events: HighJump, LongJump, Pole Vault and Triple Jump; for the throw events: Discus, Hammer, Javelin and Shotput.

In Swimming, the Olympic and Paralympic race events collected were in 5 disciplines with different distances: in freestyle, 50m, 100m, 200m, 400m, 800m and 1500m; in backstroke: 50m, 100m and 200m; in breaststroke: 50m, 100m and 200m; in butterfly: 50m, 100m and 200m; in individual medley: 150m, 200m and 400m. Relays in both sports have not been included in this study. A total number of 48 401 non-disabled performances and 34 422 Para performances were gathered.

Event groups by impairment types

For Para athletes and Para swimmers, all performances were normalized and calculated as a percentage (%) of the present world record for each classification event. Then, groups by impairment type have been set based on the IPC competition classification. For T&F Para athletes (PA), the following groupings were: athletes with visual impairment: T/F11-T/F12-T/F13; athletes with cerebral palsy: T/F35-T/F36-T/F37-T/F38; athletes with upper limb disabilities: T/F45-T/F46-T/F47; athletes with lower limb disabilities: T/F42-T/F43-T/F44-

T/F61-T/F62-T/F63-T/F64 and athletes with intellectual disabilities: T/F20. For Wheelchair athletes, the classifications were: athletes with cerebral palsy in a wheelchair: F31-F32-T/F33-T/F34; athletes with tetraplegia disabilities: T/F51-T/F52 and athletes with paraplegia disabilities: T/F53-T/F54-F55-F56-F57. For Para swimmers (PS), the groupings were: PS from classes 1 to 4 with an impairment of 3 or 4 limbs and the trunk; PS from classes 5 to 6 with an impairment of 2 limbs and the trunk or the 2 complete upper limbs; PS from class 7 to 8 Impairment of 2 lower limbs or a complete upper limb, PS from classes 9 to 10 with an impairment of a complete or incomplete lower limb or an incomplete upper limb; PS from classes 11 to 13 with a complete blindness or significant visual impairment. This grouping resulted in 105 para T&F and 87 para Swimming performances by impairment type categories.

Performance trends

To analyze and compare the performance trends of each event, performances were derived from the race times by converting them into mean speeds (m.s^{-1}) for the race events in T&F and swimming. All performances were normalized and calculated as a percentage (%) of the present world record for each event. A moving average, based on the 10-best performers over the past 4 years, has been used in order to consider the Olympic and Paralympic performance periodicity [12]. For Para T&F and Para Swimming, the moving average was calculated from 2014 up to 2020, due to the limited data available before 2010.

Then, to quantify the performance evolutions, moving average slopes between two consecutive years were computed for each year. Slopes were derived from the following equation:

$$slope(t) = \frac{\left[Y_{(t)} - Y_{(t-1)}\right]}{\left[X_{(t)} - X_{(t-1)}\right]}$$

Slopes were reported as mean ± standard-deviation per year by sport and gender for non-disabled athletes (NDA), non-disabled swimmers (NDS), PA and PS (Table 1).

In order to focus on the impact of 2020, moving average's slopes between 2010 and 2019 for NDA and NDS and between 2014 and 2019 for PA and PS have been computed for each events and reported as mean ± standard-deviation by sport and sex. Those slopes were then compared with the ones computed for 2020.

Performance levels

To estimate the recess amplitude, the performance levels per year (in %) were analyzed all events combined. We compared the 2020 performances to the 2010-2019 performances. In T&F, the performances levels were analyzed for the three groups of racing, jumping and throwing events. In swimming, the analysis regrouped all distances by stroke styles.

Stability rate of the 10-best and number of competitions held by year

To understand the renewal trend, a stability rate measured by the turnover of the 10-best athletes year after year since 2010 has been explored in each event. It refers to the number of similar athletes participating to the official competitions between two successive years, expressed in %. For PA and PS, events were analyzed by IPC classification. In some para events, too few athletes competed in 2020. These events were not considered: 209 Para events provided a reliable assessment of the stability rate.

To appreciate the number of cancelled competitions in 2020, we collected the number of event organized since 2016. For the non-disabled athletes, all international level swimming competitions on the FINA website and all IAAF competitions for the T&F events from the IAAF website have been gathered by year. For the Para athletes, all the referenced competitions

from the IPC rankings results in swimming and T&F from the IPC website have also been collected by year.

Statistical analysis

Results were reported as mean ± standard deviation. A Wilcoxon Test and a post-hoc with Bonferroni correction were performed to test if the slopes differ from 0 and if the 2020 performance levels differ compared to other years since 2010 according to the sport, discipline and gender. The same methodology was used to compared the stability rate of the 10-best between two successive years by sports. Significant results were set at $\alpha \leq 0.05$. To investigate the distribution of the number of organized competitions per year, a chi-square test for a uniform distribution was used to identify an overall effect. In the presence of a global effect, Haberman residuals were calculated and compared to the quantiles of the normal distribution (at α = *: 0.1; **: 0.05; ***0.01) to determine if the number of competitions held per year has been over or under represented. All statistical analyses were performed using R (version 3.6.2; The R Foundation for Statistical Computing, Vienna, Austria).

Ethical considerations

This study was designed and monitored by the IRMES (Institut de Recherche bio-Médicale et d'Epidémiologie du Sport) scientific committee. Data collection was compliant with the General Data Protection Regulations applied in the European Union. A declaration of the study was made and approved by the Commission Nationale de l'Informatique et des Libertés (CNIL) with the following registration number: 2216887v0.

Data availability

The data associated with the paper are not publicly available but are available from the corresponding author on reasonable request.

Results

Performance trends and levels in 2020

The distribution of the slopes applied on the moving averages (**Table 1**) is significantly different from 0 for the year 2020 ($p \leq 0.05$). A significant decreases of -0.20 ± 0.24 % for non-disabled male athletes and -0.45 ± 0.25 % for non-disabled female athletes; and -0.24 ± 0.09 % for non-disabled male swimmers and -0.27 ± 0.17 % for non-disabled female swimmers has been observed. In Para Athletes, the distribution of the slopes is significantly different from 0 for the year 2020 ($p \leq 0.05$). A significant decreases of -1.81 ± 1.25 % for male and -1.69 ± 1.31 % for female, based on slope is observed. In Para Swimmers, the distribution of the slopes is significantly different from 0 in 2020 ($p \leq 0.05$) with -1.59 ± 0.88 % for male and -1.68 ± 0.94 % for female.

The mean performance levels (in % of WR) have significantly decreased in 2020 compared to the performances of the previous years (**Table 2**). For NDA, the mean performance levels in 2020 for male and female were significantly lower ($p \leq 0.05$) compared to each year, except in 2014 for male and 2010 for female. For NDS, the mean performance levels in 2020 for male and female were significantly lower ($p \leq 0.05$) compared to each year, except in 2012 for male and 2010 for female. For PA, the mean performance levels in 2020 for male and female were significantly lower ($p \leq 0.05$) compared to each year, except for male in 2010 and for female in 2010, 2011, 2013 and 2014. For PS, the mean performance levels in 2020 for male and female were significantly lower ($p \leq 0.05$) compared to each year, except for female in 2010.

Evolutions of the 10-best performers are illustrated in four non-disabled events and four Para impairment type categories in **Figure 1** (T&F) and **Figure 2** (Swimming).

Table 1 Mean ± Standard Deviation (%) of the slopes of the moving average per year for non-disabled athletes, non-disabled swimmers, para athletes and para swimmers all events combined in Track and Field (T&F) and Swimming.

			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Non-disabled	Male	T&F	-0.06 ± 0.19*	0.02 ± 0.20	0.03 ± 0.18*	-0.01 ± 0.12	-0.06 ± 0.29	0.01 ± 0.22	-0.04 ± 0.23*	0.05 ± 0.31	0.16 ± 0.38*	0.08 ± 0.24*	-0.20 ± 0.24*
		Swimming	0.20 ± 0.09*	0.15 ± 0.08*	-0.04 ± 0.10*	-0.21 ± 0.11*	0.14 ± 0.07*	0.10 ± 0.10*	0.08 ± 0.08*	0.11 ± 0.11*	0.07 ± 0.09*	0.10 ± 0.10*	-0.24 ± 0.09*
	Female	T&F	-0.01 ± 0.22	0.03 ± 0.20	0.06 ± 0.29*	0.03 ± 0.19	-0.13 ± 0.29*	0.01 ± 0.25	0.00 ± 0.27	0.06 ± 0.23*	0.26 ± 0.27*	0.16 ± 0.17*	-0.45 ± 0.25*
		Swimming	0.23 ± 0.13*	0.21 ± 0.12*	0.06 ± 0.07*	-0.11 ± 0.17*	0.15 ± 0.12*	0.12 ± 0.10*	0.10 ± 0.09*	0.09 ± 0.13*	0.11 ± 0.12*	0.08 ± 0.10*	-0.27 ± 0.17*
Para	Male	T&F	/	/	/	/	0.51 ± 1.03*	0.85 ± 1.08*	0.86 ± 1.42*	0.87 ± 1.19*	0.80 ± 0.96*	0.74 ± 0.82*	-1.81 ± 1.25*
		Swimming	/	/	/	/	0.30 ± 0.37*	0.48 ± 0.41*	0.61 ± 0.80*	0.22 ± 0.63*	0.20 ± 0.50*	0.31 ± 0.58*	-1.59 ± 0.88*
	Female	T&F	/	/	/	/	0.58 ± 1.52*	0.78 ± 1.52*	1.08 ± 1.11*	0.93 ± 1.30*	1.00 ± 1.13*	1.05 ± 1.12*	-1.69 ± 1.31*
		Swimming	/	/	/	/	0.67 ± 0.71*	0.88 ± 0.77*	1.02 ± 1.32*	0.55 ± 1.01*	0.48 ± 0.61*	0.47 ± 0.72*	-1.68 ± 0.94*

* Indicates a mean ± SD significantly different from the value 0 ($p ≤ 0.05$).

Table 2 Mean ± Mean ± Standard Deviation (%) of the performance (in % of the WR by event) per year for non-disabled athletes, non-disabled swimmers, para athletes and para swimmers all events combined in Track and Field (T&F) and Swimming.

			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Non-disabled	Male	T&F	95.44 ± 2.67*	95.67 ± 2.68*	95.74 ± 2.84*	95.46 ± 2.86*	95.19 ± 3.31	95.69 ± 2.65*	95.58 ± 2.62*	95.64 ± 2.40*	95.83 ± 2.47*	96.03 ± 2.60*	94.79 ± 2.76
		Swimming	96.59 ± 1.05*	96.88 ± 1.10*	97.20 ± 1.11	97.11 ± 0.93*	97.16 ± 0.96*	97.3 ± 0.89*	97.53 ± 1.03*	97.55 ± 0.91*	97.46 ± 0.90*	97.70 ± 0.98*	96.56 ± 1.05
	Female	T&F	93.87 ± 3.26	94.07 ± 3.53*	94.66 ± 2.97*	94.17 ± 3.29*	93.33 ± 3.86	94.11 ± 3.55*	94.66 ± 3.34*	94.43 ± 3.57*	94.38 ± 3.52*	94.75 ± 3.60*	92.87 ± 3.75
		Swimming	96.36 ± 0.73	96.70 ± 0.75*	97.01 ± 1.02*	97.06 ± 0.91*	96.97 ± 0.90*	97.16 ± 0.93*	97.43 ± 1.09*	97.42 ± 1.03*	97.40 ± 0.96*	97.49 ± 0.98*	96.36 ± 1.09
Para	Male	T&F	83.01 ± 11.64	84.43 ± 11.26*	85.61 ± 11.26*	84.50 ± 10.93*	84.90 ± 10.29*	87.56 ± 9.32*	88.75 ± 8.33*	88.01 ± 8.92*	88.10 ± 8.46*	90.53 ± 7.23*	81.35 ± 12.24
		Swimming	87.10 ± 7.68*	88.19 ± 7.27*	89.22 ± 8.33*	86.91 ± 9.10*	87.86 ± 8.18*	89.68 ± 6.82*	91.16 ± 6.74*	87.59 ± 8.38*	88.72 ± 8.70*	91.09 ± 7.10*	84.96 ± 9.54
	Female	T&F	77.29 ± 14.21	79.33 ± 14.27	81.07 ± 13.26*	78.75 ± 14.49	79.43 ± 14.75	82.45 ± 13.7*	84.94 ± 12.53*	82.58 ± 13.13*	83.25 ± 12.36*	86.66 ± 11.13*	78.02 ± 14.62
		Swimming	83.64 ± 9.46	84.97 ± 8.56*	86.03 ± 9.75*	84.78 ± 9.17*	86.30 ± 7.48*	88.23 ± 7.00*	89.98 ± 6.53*	87.01 ± 8.03*	88.31 ± 8.14*	90.19 ± 7.09*	83.11 ± 9.68

*Indicates a mean ± standard deviation significantly different from the performances in 2020 ($p ≤ 0.05$).

The analyses in T&F and swimming by discipline related to the slopes and performance levels are presented in **supplementary files**.

Performance trends from 2010 to 2019

Over the 2010 to 2019 period, significant performance improvements based on the slope (p≤0.05) of 0.05 ± 0.11 %, 0.06 ± 0.05 %, 0.09 ± 0.05 % for female's NDA, male's NDS and female's NDS respectively, are measured. Among male NDA, the increase of 0.03 ± 0.11 % was not significantly different from 0.

From 2014 to 2019, performances significantly increased (p≤0.05) from 0.93 ± 1.00 %, 1.05 ± 1.02 %, 0.32 ± 0.35 % and 0.74 ± 0.75 % for male's para athletes, females' para athletes, male's para swimmers and female's para swimmers respectively.

Stability rate

All sports and genders combined for NDA and NDS, the stability rate was significantly lower in 2020 with 38.18 % as compared to 55.76 % in 2019. Between 2020 and 2019, the stability rates of non-disabled significantly decreased of 16.06 % among males (Table 3) and 19.09 % % among females. Following the Olympic Games in 2012 and 2016, a less significant decreased was measured in 2013 and 2017 (**Table 3**).

All sports and sexes combined for PA and PS, the stability rate was significantly lower in 2020 with 38.90 % as compared to 59.95 % in 2019. Between 2020 and 2019, the stability rates significantly decreased of 18.50 % among Para males (Table 3) and 25.97% among Para females. Following the Paralympic Games in 2012 and 2016, a less significant decrease was measured in 2013 and 2017 (Table 3).

Table 3 Mean stability rate (%) according to the previous year from 2010 to 2020 of the non-disabled athletes, non-disabled swimmers, para athletes and para swimmers 10-best for male and female all sports combined, all Track & Field (T&F) events combined and all Swimming events combined

	%		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Non-disabled	Male	All	/	52.12	47.27	47.58	49.39	51.82	52.73	43.64*	53.03*	56.06	40.00*
		T&F	/	45.79	45.26	47.89	43.16	47.89	46.32	37.89	48.42*	53.68*	34.21*
		Swimming	/	60.71	50.00*	47.14	57.86*	57.14	61.43	51.43	59.29	59.29	47.86*
	Female	All	/	49.09	57.27*	47.88*	51.21	53.94	55.76	53.94	54.55	55.45	36.36*
		T&F	/	46.84	50.53	45.26	47.89	49.47	52.11	54.74	49.47	54.74	32.11*
		Swimming	/	52.14	66.43*	51.43*	55.71	60.00	60.71	52.86	61.43	56.43	42.14
	All		/	50.61	52.27	47.73*	50.30	52.88	54.24	48.79*	53.79*	55.76	38.18*
Para	Male	All	/	65.69	69.17*	61.01*	63.40	63.28	70.84*	60.35*	58.21	58.04	39.54*
		T&F	/	59.07	64.61*	58.22*	59.46	62.54	67.75*	64.31*	59.09*	59.91	35.21*
		Swimming	/	73.10	74.33	64.17*	68.00	64.17	74.50*	55.67*	57.17	55.83	44.67*
	Female	All	/	68.61	72.57*	64.64*	64.05	64.91	72.67*	62.28*	62.92	63.79	37.82*
		T&F	/	66.08	71.00	62.97*	59.69	63.29	71.95*	65.37*	63.35	62.62	36.10*
		Swimming	/	71.68	73.51	65.32*	68.62	66.22	73.96*	57.84*	61.08	63.72	39.73*
	All		/	66.84	70.31*	62.16*	63.6	63.8	71.61*	60.89*	59.73	59.95	38.90*

* indicates a significant difference in the year's stability rate compared to the previous year ($p \leq 0.05$).

Number of competitions

In 2020, a significant decrease in the number of organized competitions was observed (Figure 3). For Para athletes and Para swimmers, the number of competitions dropped significantly after a year of increases in 2019.

Discussion

In 2020, the level of performances in all Olympic and Paralympic studied events has decreased significantly compared to the previous years. Such declines in performance have not been observed except during both World Wars. The measured recess corresponded to a 6 to 10 years setback. This recession occurred in a context of stagnating male performance in Track and Field, slight increases in female Track & Field and swimming, and an increase among Para athletes and swimmers. In 2020, the number of new athletes in the Top 10 was significantly higher and the number of organized competitions significantly lower as compared to the other years.

Performance trends

In 2020, performances have significantly decreased for NDA, NDS, PA and PS. This trend could be due in part to a lack of training, generating a detraining [27,33] and a decrease in performance capacity [10,11,24,25], or to travel restrictions with a deficit of competitions.

In Track and Field, among non-disabled athletes, the performance decrease experienced in 2020 is similar to the decrease that followed the second World War [12,15] as shown in Figure 1 for NDA. In the last decade, performances have slightly increased among non-disabled female athletes. The other T&F events have stopped progressing since 1993 [12,15]. Over this period, few regulatory or technological developments have emerged. Since 2017, the first carbon shoes have helped to break many records on long distance running events. This reopened the debate on the technological impacts on the running economy and biomechanical gains [34]. However, this contribution remains limited for the moment for the global T&F evolution.

Among Para athletes, the hindsight to analyze the performance trends is more limited compared to NDA. In 2020, performances have considerably dropped after a significant progression over

the 2014-2019 period. Among Paralympic sprinter amputees [35], the mean performance of medalists between 1976 and 2012 has increased consistently and confirmed our study results.

In non-disabled swimming, a similar decline happened a few years ago. Indeed, the last equivalent recess occurred in 2010 following the ban of polyurethane swimsuits that contributed to a large sample of records in 2008 and 2009 [36]. During the following decade, performances progressed again with higher margins for improvement than in T&F. Since the ban of polyurethane swimsuits, the swimmers compete in bodyskins, kneeskins or jammers and use new angled starting blocks that still provide some gains [36].

In 2020, the swimming Paralympic performance also declined significantly after a 2014-2019 progression phase. From 1992 to 2012, Paralympic swimming performances have progressed [37], by 0.5% per year for males and female in the 100m freestyle [21], a faster progression than in Olympic swimming.

Our study highlights the 2020 large performance decrease in both para and non-disabled swimming.

Performance levels

For non-disabled T&F performances, the observed drop ranged from 1.2 % for males to 1.88 % for females between 2019 and 2020. This recess corresponds to an equivalent setback of 6 years (i.e. back to the 2014 performances) for both genders. In swimming, all events combined, a decline of 1.1 % has been observed for both genders which corresponds to an 8 - 10 years recess.

Para athletes and PS have experienced a much greater decline than NDA and NDS. The performance loss ranged from 8.6 % for females to 9.2 % for males in Para T&F, corresponding to the level reached in 2010 for males and 2014 for females, all events combined. In swimming, with a loss of 7.1 % for females, the performances referred to the 2010 performance level. For

males, the decline in performance is superior to the studied period and does not allow the quantification of the setback.

The analysis of performances showed a 4 years periodicity with an increase each Olympic years and a decrease the following year [15,21,23,24]. This tendency shown among Para events reproduces what was already demonstrated among non-disabled disciplines [15].

The gap between Paralympic and non-disabled athletes & swimmers

The decline of performances in 2020 was more important for PA and PS compared to NDA and NDS. The lockdown was perceived by Paralympic athletes more negatively than Olympic athletes in their training and performance[31]. Moreover, this difference could be due to a lower density of athletes and a higher variability of performance within and between each classes of impairment [37–39]. Depending on the classification, some events have considerable variability in performance within the 10 years of follow-up and a wider gap to the best performance which could confirmed a higher variability.

Depending on the year, performance levels ranged from 93% to 97% of the best performance among NDA and between 77% and 91% for the PA. These levels of performance underline a potential improvement that could be more important for PA than for non-disabled ones. This observation has been confirmed in amputee sprinting which has seen a greater and faster rate of performance progression [35].

Stability rates and competition number

In 2020, the stability rates of the 10 best athletes are lower than in 2019, suggesting that some of the best athletes may not have competed in 2020, depending on their nation policies. In most cases, Olympic and Paralympic periodicity was well reflected in the stability rate of each

Olympic year in 2012 and 2016. The 2020 rates decrease were almost twice lower compared to the stability rate occurred in 2013 and 2017.

This observation is also confirmed in swimming among the top world-ranked swimmers and could be explained by the fact that the training and periodization procedures of swimmers are carefully designed to achieve the peak performance in the most important competitions [23]. In addition, the 2020 decrease in performance, level and stability may also be due to a lower number of organized competition because the pandemic led to the postponement or cancellation of many competitions and championships [3,4]. Swimming has been the most impacted discipline with a reduction of 83% and 51% of the non-disabled and Para events respectively.

Still on the edge?

Many studies have focused on the evolution of non-disabled records. The democratization of sport as well as its professionalization explain the progression of the best performances [12,13,16,17,40]. This optimization is also favored by technological advances and innovations dedicated to sport. Also, the geopolitical context plays a determining role in the quest for records [13,41] but what will be the priorities in the years to come? Indeed, this pandemic dramatically upset all areas of human life, leading to a profound change that will deeply influence the societies, their economy and most of their components including the elite sport field. As a result, annual best performances who reflect the limits of the present capacities, may also be impacted.

Limitations

The current study has several limitations. First, applying a mathematical function such as Berthelot et al [12,15] on the Top 10 performance trend considering the stability rate and the number of competitions would allow another vision on the last decade trends. Secondly, the number of competitions analyzed in non-disabled and Paralympic athletes come from different

sources. The available competition data on the IPC website are taken from local, national or international meetings. Lastly, measuring the impact of the pandemic situation on the top 10 by nation according to the containment or stringency index would also be relevant [33,42]. Additional work combining monitoring test and training load during the 2020 years may provide a clue on the resilience of the sport field in the present context.

Conclusion

The year 2020 will remain unique in the sport history as it has been for all other human activities. Its impact on the performances of the best international athletes has been considerable. Such declines have not been observed in the last 10 years corresponding to a 6 – 10 years setback. The following years will tell how societies will recover from such a recess.

conceived and designed the research. Julien Schipman, Guillaume Saulière, Imad Hamri, Yann Rivallant, Jean-François Toussaint, and Adrien Sedeaud performed and analyzed the research. Julien Schipman and Adrien Sedeaud wrote the manuscript. All authors read and approved the final manuscript.

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42. De Larochelambert Q, Marc A, Antero J, Le Bourg E, Toussaint J-F. Covid-19 Mortality: A Matter of Vulnerability Among Nations Facing Limited Margins of Adaptation. Front Public He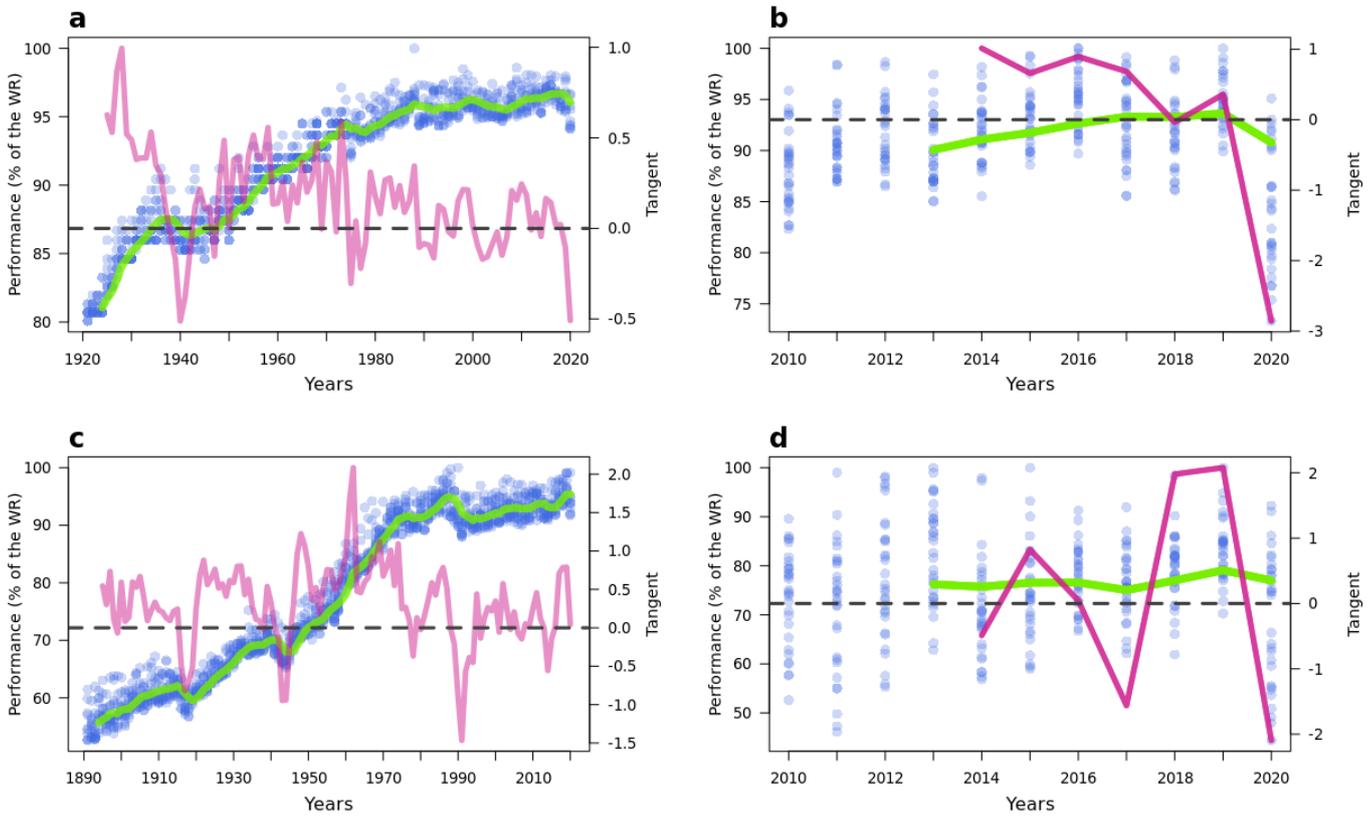alth [Internet]. 2020 [cited 2021 Mar 12];8. Available from: https://www.frontiersin.org/articles/10.3389/fpubh.2020.604339/full

Figure 1. Evolution in % of the WR of the 10-best performers per year in Track and Field in several events (left scale). The green curve represents the moving average of the 10-best performances per year during the 4 previous years. The pink curve represents the slope applied on the moving average (right scale). The graphs on the left refer to: (a) the non-disabled female athletes on the 100m race event, (c) the non-disabled male athletes in the shotput event. The graphs on the right refer to: (b) the visually impaired female para athletes (T11, T12, T13) on the 100m race event, (d) the cerebral palsy male para athletes in wheelchair (F31-F32-F33) in the shotput event.
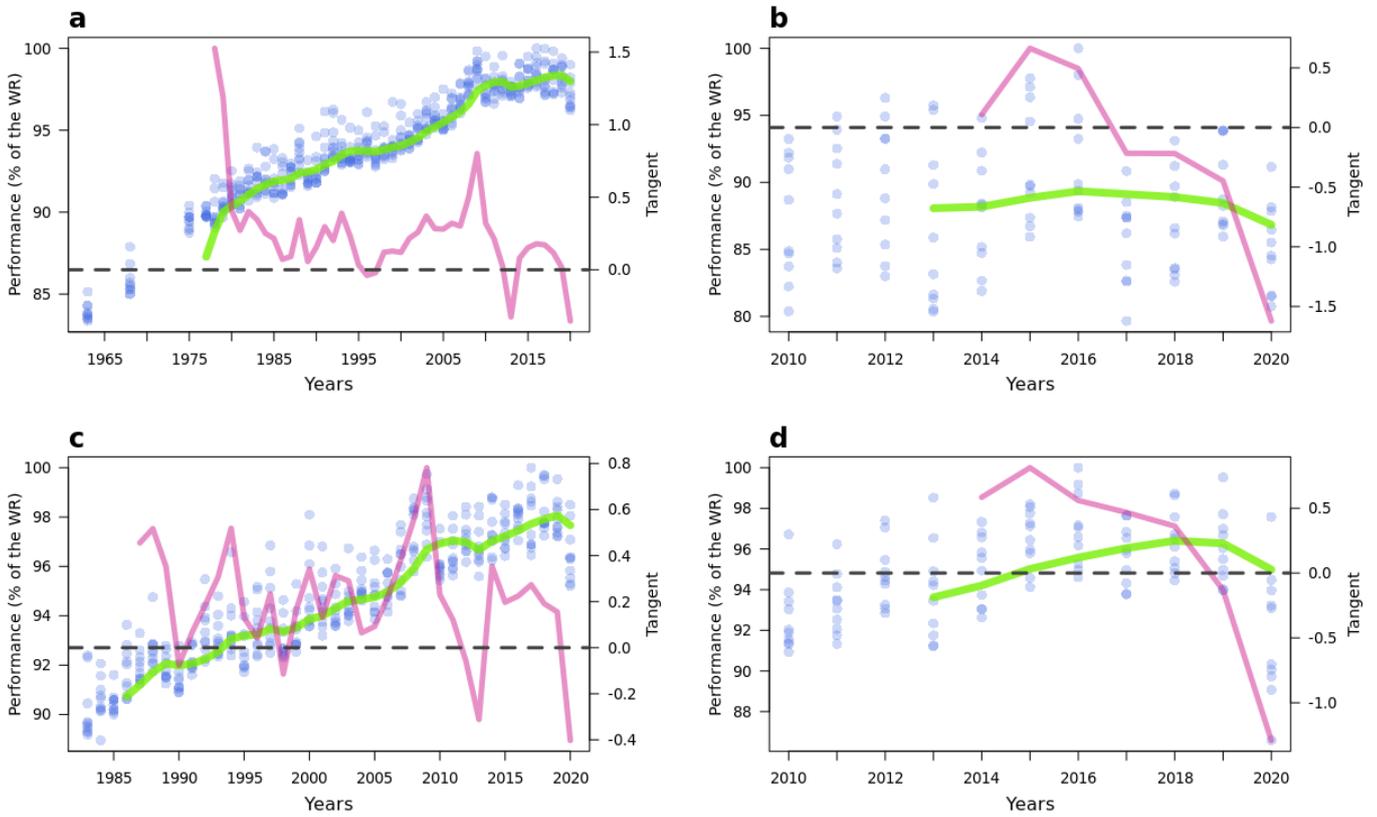
Figure 2. Evolution in % of the WR of the 10-best performers per year in swimming in several events (left scale). The green curve represents the moving average of the 10-best performances per year during the 4 previous years. The pink curve represents the slope applied on the moving average (right scale). The graphs on the left refer to: (a) the non-disabled male swimmers on the 100m backstroke race event, (c) the non-disabled female swimmers in the 50m freestyle. The graphs on the right refer to: (b) the S5-S6 male para swimmers on the 100m backstroke race event, (d) the S9-S10 female para swimmers in the 50m freestyle.
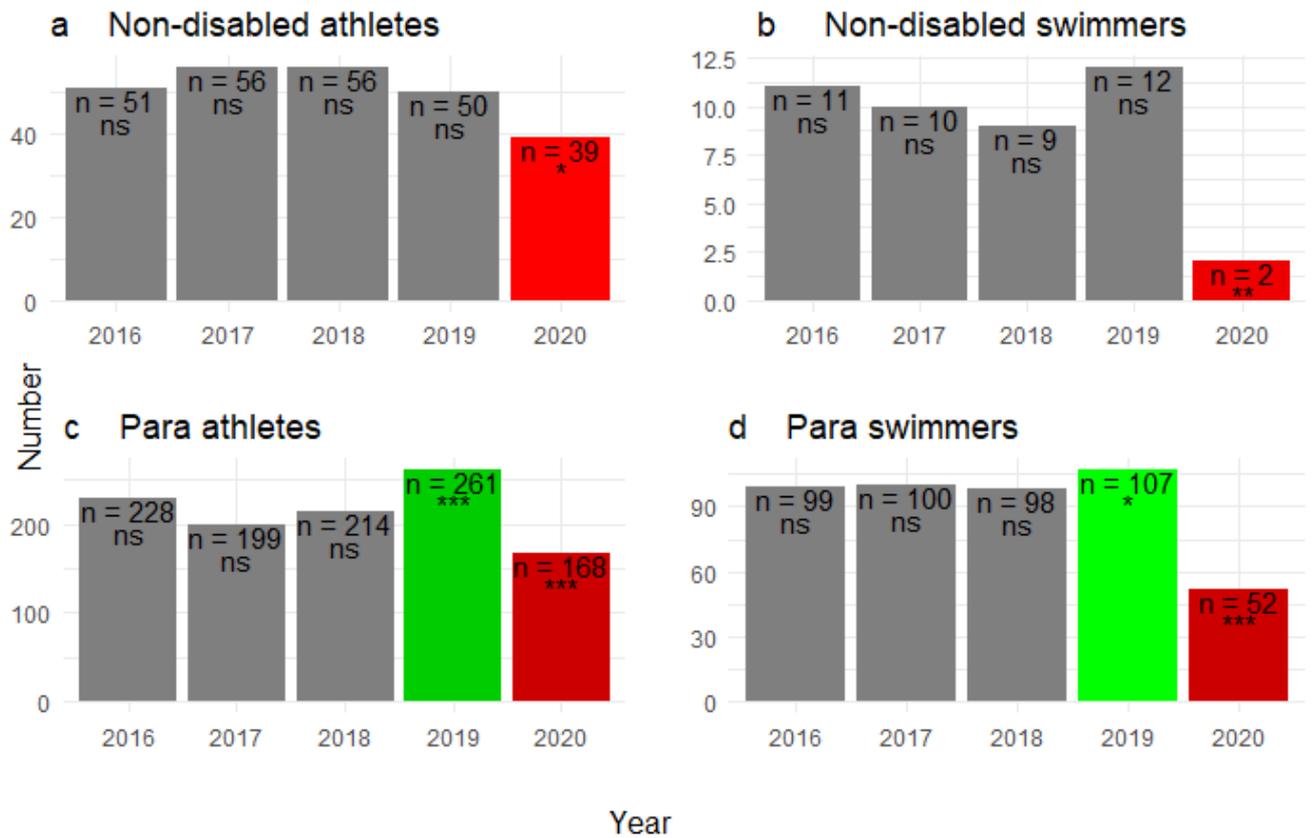
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Figure 3. Number of competitions organized by year for non-disabled athletes (a) and non-disabled swimmers (b) (International level) and para athletes (c) and para swimmers (referenced competitions from the IPC rankings results) in Track and Field (T&F) and swimming from 2016 to 2020. *, **, *** indicate a significant over or under representation.